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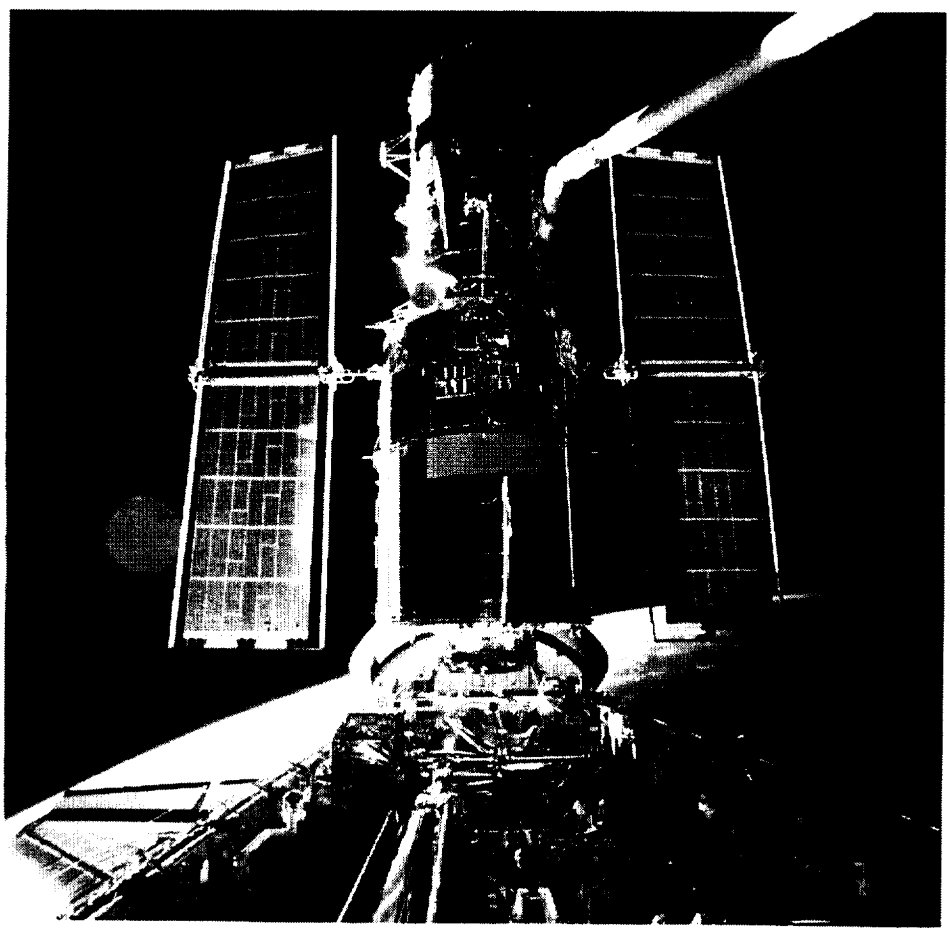

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STS-61 Mission Director's Post-Mission Report Abstract

This report details events that occurred before and during the STS-61 Space Shuttle mission and makes recommendations for future mission execution.

The Hubble Space Telescope (HST) First Servicing Mission (SM-1) was a highly successful space flight. The HST hardware installation tasks designated as success criteria by the National Aeronautics and Space Administration (NASA) were all accomplished. All planned optional tasks were completed as well. The new optical instruments were later demonstrated to have corrected the spherical aberration present when the telescope was placed into orbit in April 1990.

Key to the success of the HST SM-1 was the fact that the HST had been designed and built to be maintained by astronauts during extravehicular activity (EVA). The success of this mission came also as a result of total commitment to the mission by NASA and its contractor team. This mission was probably the most complex Shuttle mission flown to date. NASA was willing to devote the necessary resources to ensure its proper completion.

Because of the complexity and importance of this mission, NASA management established a number of independent review groups to assess the management, design, planning, and preparation for the mission. The review groups made key and timely recommendations which caused or contributed to a number of mission enhancements.

This report recommends the following.

- A mission management plan for each complex mission
- Appointment and empowerment of a mission director for each future highly complex mission
- Continued use of coordinated independent peer review for critical missions
- Extended template for complex missions for earlier completion of mission preparation milestones
- Uniform NASA-wide EVA hardware certification requirements
- Single point of control for mission safety and assurance activities
- Single EVA safety process
- Central coordinated strategic plan for NASA public affairs activities for high profile missions

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Executive Summary

The Hubble Space Telescope (HST) First Servicing Mission (SM-1) was a highly successful space flight (STS-61). The success criteria established by the National Aeronautics and Space Administration (NASA) before the mission, consisted of the successful replacement of the HST's solar arrays (SAs), rate sensor unit no. 2 (RSU 2) and wide field/planetary camera (WF/PC); installation of the corrective optics space telescope axial replacement (COSTAR) and the magnetic sensing system no. 1 (MSS 1); and replacement of HST's RSU 3, electronic control unit no. 3 (ECU 3), and solar array drive electronics no. 1 (SADE 1). Not only were all these tasks performed, making the mission a success, but also all the planned secondary tasks were accomplished, namely installation of the Goddard high resolution spectrograph (GHRS) redundancy kit, the coprocessor for the HST main computer and MSS 2 and replacement of both types of RSU fuse plugs and ECU 2.

The many tasks of the mission occurred remarkably close to the way that the tasks were planned. Launch of the Orbiter Endeavour occurred on December 2, 1993, at approximately 3:27 AM CST. On the first and second flight days Orbiter systems were made ready for rendezvous with and capture of the HST and for the EVAs.

On the third flight day the crew performed rendezvous maneuvers, established communications with the HST, grappled the HST, and berthed it in the Orbiter payload bay, all according to plan.

On the fourth flight day the first extravehicular activity (EVA) occurred, during which replacements were performed of RSU 2, RSU 3, ECU 1, ECU 2, and the RSU fuse plugs. Preparations for the next day's SA replacements also were made. Unexpected difficulty in closing the RSU compartment doors was eventually overcome with the use of a payload retention device strap and the efforts of both EVA crewmembers. Physical distortion in one the SAs prevented its complete retraction.

On the fifth flight day the distorted SA was manually jettisoned. The jettison procedure had been practiced during one of the joint integrated simulations (JISs) before the mission, and it did not negatively affect the EVA schedule. Both SAs were successfully replaced during this second EVA.

The third EVA, performed on the mission's sixth day, included the WF/PC replacement and the installation of both MSS modifications. Deterioration of one of the old MSS covers was discovered during was discovered during the EVA.

During the fourth EVA on the next day, installations of the COSTAR and of the coprocessor occurred with no significant problems. Also during this EVA the crewmembers removed the insulated covers of several pieces of flight support equipment. Two of these covers were modified after the EVA for use as covers to be installed on both MSSs during the fifth EVA.

Early on the eighth flight day, the Orbiter was boosted to an orbit of approximately 321 by 320 nautical miles. Also on the eighth day, commands to the HST were unable to move the SA primary deployment mechanisms, resulting in a decision to have the EVA crewmembers manually deploy the SA booms during that day's EVA. During this fifth and final EVA, the crewmembers performed the replacement of the SADE 1, manually deployed the SA booms, installed the GHRS redundancy kit, and installed the new covers on both MSSs. Commands sent to the HST successfully unfurled both SAs. Data problems encountered following the EVA were eventually attributed to a malfunctioning channel in one of the HST's data interface units (DIUs). When the DIU was switched to an alternate channel, it functioned properly.

The HST was redeployed on flight day 9.

The crew was given a day off on flight day 10.

On flight day 11, the Commander and Pilot practiced Orbiter approaches and landings using the portable in-flight landing operations trainer (PILOT).

During the twelfth flight day the Endeavour landed at Kennedy Space Center at approximately 11:25 PM CST on December 12, 1994.

During the mission the replacement hardware was shown to be electrically functional. The new optical instruments were later demonstrated to have corrected the spherical aberration present when the telescope was placed into orbit in April 1990. These new instruments improved the telescope's optical performance to levels expected from the original design.

Key to the success of the HST SM-1 was the fact that the HST had been designed and built to be maintained by astronauts during EVA. Astronauts and other EVA experts were very heavily involved in the HST design process. While budget limitations during the building of the HST prevented the incorporation of EVA-friendly features into every component, nearly all the components were made at least EVA-compatible, meaning that even though special tools or procedures would still have to be developed to work on the component, it is accessible and replaceable by an astronaut wearing a pressurized extravehicular mobility unit (EMU).

The success of this mission came also as a result of total commitment to the mission by NASA and its contractor team. The fact that the HST was launched containing a flawed mirror, the fact that a large number of components were in need of servicing or replacement, and the fact that not all of these components were EVA-friendly, combined to make this mission probably the most complex Shuttle mission flown to date. Multiple NASA centers and numerous contractors were involved in the design, development and execution of the telescope and EVA hardware and the formulation of the procedures for the servicing mission. NASA was willing to devote the necessary resources to ensure adequate high-fidelity training for the flight crew and ground support personnel. Although the ratio of EVA training hours to in-flight EVA hours was not greater than that of some earlier Shuttle EVA missions, and because the five EVAs of HST SM-1 were the most ever conducted during a mission, the total EVA training load was also the greatest of any Shuttle mission to date. The quality of training was also higher than that for previous missions because of increased emphasis on end-to-end EVA and remote manipulator system (RMS) training and contingency procedures training. A large number of simulations were conducted for this mission, including internal simulations held at Goddard Space Flight Center (GSFC), Johnson Space Center (JSC), and Marshall Space Flight Center (MSFC) and JISs involving the entire mission team. Every EVA was simulated with EVA crewmembers in underwater training facilities during JISs.

Because of the complexity of the mission and of its importance to NASA and to the public, NASA management took extraordinary steps to ensure its success. A number of independent review groups, both inside and external to NASA, were established to assess the management, design, planning and preparation for the mission. These groups produced a large number of recommendations, most of which are discussed in detail in this report. While some might argue that the review groups made many recommendations that would have been accomplished anyway in the normal course of mission activities, the Mission Director believes that the review groups made key and timely contributions in a number of areas.

Recommendations to evaluate STS-61 hardware and EVA procedures on previous missions led to the realization that the planned Orbiter attitude for some of the EVA tasks would result in an environment too cold for the EVA astronauts. If this discovery had occurred during STS-61, significant negative impact to the servicing mission could have occurred.

A review group's recommendation to upgrade the breathing system and remote manipulator system (RMS) simulator in the Neutral Buoyancy Simulator (NBS) at MSFC helped to bring about those improvements. Although there was a significant delay in the implementation of these recommendations, both were completed in time to be used for final end-to-end training for the mission. This upgraded capability for integrated EVA and RMS training was key to the success of the mission.

The recommendation to assign and train a backup crew for the mission resulted in the designation of the STS-61 EVA Capsule Communicator (Capcom) to also be the backup EVA crewmember. This assignment proved to be beneficial in increasing the Capcom's familiarity with the EVA tasks and in allowing greater flexibility in the scheduling of crew training events. **The Mission Director recommends that for future critical EVA missions, NASA consider the assignment of a crewmember to serve as both EVA Capcom and backup EVA crewmember.**

Review group recommendations to perform JISs for each EVA with crewmembers in underwater training facilities and with participation of mission management provided the opportunity to refine normal procedures and mission team coordination and to train for real-time contingency operations that were stressed during the simulations.

A review group recommended that as many as possible of the commands to the HST be sent from within the Orbiter instead of from the ground to prevent delays of EVA activities caused by waiting for the ground commands. Partly as a result of practice that occurred during the JISs, HST commanding that was performed during the STS-61 EVAs was well coordinated and timely. **The Mission Director recommends that the balance of on-board versus ground commanding of payloads continue to be given high priority during mission planning. The amount of commands that can be sent by the flight crew should be maximized to the extent practical, and the commanding protocols should be thoroughly rehearsed and evaluated during JISs.**

An EVA assessment group's recommendation to move EVA tools from the payload bay into the Orbiter cabin resulted in the saving of valuable EVA time.

On the basis of the positive results from independent reviews, the Mission Director recommends that the use of independent peer review be continued for critical missions. A multidisciplinary team having relevant expertise should be established to perform a thorough and comprehensive independent assessment of flight readiness. The team activities should be coordinated with standard mission milestones to impart minimal interference to mission preparation activities.

The use of a single team as mentioned above is the preferred form of peer review, but if reviews are to performed by multiple independent organizations, their activities should be consolidated to the maximum extent possible and performed in coordination with established program and mission milestones to minimize duplication of effort by those preparing for the mission. Reviewing organizations should be sensitive to their potential for interfering with mission preparation activities.

A recommendation that NASA establish a mission manager for this mission resulted in the appointment by the NASA Associate Administrator for Space Flight of Mr. Randy H. Brinkley as the STS-61 Mission Director on December 15, 1992. In this position, Mr. Brinkley was tasked "to coordinate the efforts of the team working to safely and successfully accomplish the HST Servicing Mission." Mr. Brinkley chaired the Mission Coordination Team, which was established to coordinate Level I activities and to oversee Level II and III management activities during mission preparation. The team included management representatives of the Space Shuttle and HST Program offices. The Mission Director served to coordinate and expedite both the Space Shuttle and HST Programs' responses to the recommendations. The Mission Director also served to help focus and consolidate the efforts of the review groups to minimize impacts to mission preparation activities. The Mission Director also coordinated communication with and external inquiries from the General Accounting Office (GAO) and Congressional staff members.

The STS-61 Mission Director recommends that NASA continue the practice of appointing mission directors for highly complex space flights as designated by the NASA Administrator. A mission director should provide management direction and oversight of the integration, flight preparation, and mission training processes and accomplishment of the mission. A mission director should be responsible for proper coordination among the various NASA offices, NASA centers, NASA program managers and personnel external to NASA who have a responsibility for the safe and successful execution of the mission. A mission director should be responsible for ensuring compliance with all safety and mission assurance requirements and for resolution of key issues involving any aspect of the mission. A mission director should also co-chair the Mission Management Team. A mission director should provide concurrence in the mission's goals, objectives, priorities, and policies, in crew selection, in cargo mix, in the determination of flight readiness of all disciplines participating in the mission and of the flight hardware, and in the date and time of launch.

Also in response to the recommendation to establish a mission manager, the Space Shuttle Program named Mr. Hal Lambert as Mission Manager for STS-61 on February 18, 1993. In this position, Mr. Lambert was in charge of a Level III HST SM-1 Management Team. The team was "established to provide management overview and resolution of issues associated with the mission. This team [was] responsible for coordinating the integration activities between GSFC, JSC, and KSC [Kennedy Space Center], maintaining overall program schedules, ensuring mission capabilities and mission priorities [were] compatible and directing the activities in support of this mission as necessary to ensure mission success." The team was "not intended to replace the existing management structure, but to facilitate problem resolution and increase the mission visibility throughout the existing system. The HST SM-1 Management Team [was to] work with the Mission Director to keep him informed of the status and progress of HST repair preparation." Following STS-61, the Space Shuttle Program implemented the practice of assigning mission managers within the Integration and Operations Office for each Shuttle mission.

Recommendations from several reviews focused on the great need to present to the public the proper perspective of the mission. NASA public affairs activities for STS-61, while extensive, were not well coordinated among the significant mission participants. The Mission Director recommends that for missions having high

public interest, a well-coordinated strategic plan for public affairs be implemented and be under the control of a single NASA office. The plan should include the publication of a clear set of mission success criteria, and a plan of action to be followed if the mission were not a success.

Recommendations to take extraordinary steps to ensure that the mission payload hardware would be protected from contamination during preflight processing resulted in the implementation of a special contamination control plan at KSC. However, in spite of the extra precautions taken as a result of this plan, windblown sand and debris entered the payload change-out room while payload hardware was in the room. **The Mission Director recommends that for all missions having payloads sensitive to contamination, there be in place at the launch site a comprehensive plan to protect the payloads from all sources of contamination, including human-generated and natural sources.**

The Mission Director commends the HST and Space Shuttle Programs for the complex communications and coordination efforts by the various NASA centers and contractors and for their accomplishments in unifying the work of the varied disciplines. However, some problems did occur because of the lack of proper coordination. The most significant of these problems are summarized here, with recommendations for future courses of action.

GSFC tool coatings were designed on the basis of outdated Orbiter attitude profiles. JSC and GSFC used different conventions for numbering bits in their digital payload data processing schemes using the Shuttle general processing computer. These kinds of problems might have been detected sooner, or even prevented if technical meetings had been more detailed, more frequent, and started earlier.

In a number of different instances both before and during the mission, mission personnel met with difficulty in transferring technical data from one location to another. **The Mission Director recommends that the use of electronic communications be maximized for future missions, both during mission preparation and during the mission itself. Methods of transfer of verbal, data, graphical and pictorial information should be readily accessible by the entire mission team.**

The Mission Director recommends that a computerized system be developed to support decision making during EVA replanning. The system should provide the flight control team with access to EVA timelines, procedures, data for tools, hardware, and payload systems, photographs and engineering drawings.

Another example of lack of coordination is that JSC and GSFC used different philosophies in the development of EVA tool certification and verification requirements. **The Mission Director recommends that NASA establish a single set of requirements for EVA hardware. JSC's newly formed EVA and Crew Equipment**

Project Office is a start at accomplishing this goal, but the office must be given the authority to control all EVA hardware.

Earlier designation and participation of the EVA crew would have resulted in more crew involvement in the design of EVA tasks, especially the coprocessor and SADE tasks, resulting in easier EVA operations. **The Mission Director recommends that complex Shuttle missions be performed using an extended flight production template, with milestones, including the designation of key crewmembers, occurring earlier than for standard missions.**

For STS-61, mission support personnel who were to support night shifts and especially the EVAs were generally given reduced preflight work schedules immediately before the mission to allow them to voluntarily adjust their sleep schedules. However, there was not a formal team-wide plan to ensure that this happened for all critical personnel. **The Mission Director recommends that for critical missions that include crew operations (especially EVAs) occurring during normal sleep hours, a formal plan be implemented to facilitate the necessary sleep shifting of the mission support personnel (including management) before launch.**

During the preparation for this mission there was discussion of the possibility of an astronaut's performing an EVA on each of two consecutive days. This would be a violation of one of the crew constraints contained in Appendix K of the Space Shuttle Crew Procedures Management Plan. This constraint could be waived during a mission, but there was a confusion over whether a flight director alone or only the Mission Management Team (MMT) had the authority to waive it. **The Mission Director recommends that the authority to waive Appendix K constraints be clearly defined.**

Another area in need of greater definition of roles and responsibilities is the total area of mission assurance. For STS-61 there was no single person or organization actively working to coordinate the efforts to enforce compliance with the various sets of safety requirements. There was also no discernible overall risk management or mission assurance effort for the mission. **The Mission Director recommends that for each mission a single point of contact be designated who is actively responsible for all aspects of mission assurance and safety, including payload, Orbiter, operational, and EVA safety.**

The Mission Director also recommends that NASA develop a single process that is responsible for all aspects of EVA safety and mission assurance.

To provide a tool for the implementation and coordination of many of the above recommendations, the Mission Director recommends the development of a management plan for complex missions. It should be developed early in the mission planning flow and should be coordinated among the various elements of the mission team.

Introduction

On December 15, 1992, NASA Associate Administrator for Space Flight named Mr. Randy H. Brinkley as the STS-61 Mission Director. Mr. Brinkley assembled a small staff at the Johnson Space Center and his office was operational by mid-January, 1993.

This report details events that occurred before and during the STS-61 Space Shuttle mission, the Hubble Space Telescope First Servicing Mission. Information included in this report was obtained from records maintained by the Mission Director and his staff, from post-mission submittals solicited from and provided by the various engineering and operations disciplines that had participated in the preparation and execution of the mission, and from presentation materials and minutes from mission planning and review meetings. Opinions expressed in the body and first appendix of this report are those of the STS-61 Mission Director, and not necessarily those of the other contributors.

The recommendations contained in this report include suggestions for improved mission execution. Some of these recommendations can be considered lessons learned, but many others are ideas that have been in common use by NASA and its contractors. They are included here for consideration in executing future HST servicing missions as well as the assembly and maintenance of the International Space Station.

Pre-Mission Events

Pre-mission events significant to the experience base of mission management are detailed in chronological order in this section. Mission Director's recommendations resulting from these events are presented in boldface type following the event(s) that prompted the recommendation(s).

Planning and preparations for the Hubble Space Telescope (HST) First Servicing Mission (SM-1) were well under way even before the HST was deployed in April 1990. (The first HST Maintenance Mission Payload Operations Working Group [POWG] meeting was held in August 1988.) However, the focus of the mission planning changed dramatically following the discovery of spherical aberration in the HST images resulting from a manufacturing error in the primary mirror. The mirror surface had been misshaped by 0.002 mm. The wide field/planetary camera no. II (WF/PC II) had been planned before the optical flaw was discovered. Its design was changed to compensate for the problem in the primary mirror. The corrective optics space telescope axial replacement (COSTAR) was designed to correct the focus of the light entering the faint object camera (FOC), the Goddard high resolution spectrograph (GHRS) and the faint object spectrograph (FOS). Problems caused by jitter induced into the HST by solar array (SA) thermal distortions led to the decision to build and install new arrays. Concern over long-term reliability of the gyroscope systems, or rate sensor units (RSUs), resulted in the decision to replace two of the three RSUs on the HST. As of February 1992, the baselined tasks for HST SM-1 were those involving the COSTAR, the WF/PC II, new SAs, and two RSUs.

On March 16, 1992, Dr. Story Musgrave was announced as Payload Commander for STS-61.

From March 26 through April 14, 1992, an extensive series of sixteen tests was conducted in MSFC's Neutral Buoyancy Simulator (NBS). In these space-suited underwater runs with eleven astronauts (including Dr. Story Musgrave and Mr. Greg Harbaugh) as subjects for twelve of the runs, EVA procedures and preliminary timelines were developed or enhanced for replacement tasks for the SAs, the COSTAR, the RSUs, the electronic control units (ECUs), and the WF/PC II. This series of evaluations was also used to assess the design concepts for the WF/PC installation tool (WIT), the small orbital replacement unit (ORU) protective enclosure (SOPE), the WF/PC mirror cover, the GHRS "H" cable, and the DF-224 coprocessor.

Results of these tests are presented in HST SM 92.1 Executive Summary Report, dated April 27, 1992. One of the recommendations in the report is that "every effort should be made to fund an RMS [(remote manipulator system) simulator] with flight-like characteristics.... The present configuration of a single joint RMS and its limitation to station-keep will seriously impact crewmember training." The report also mentions that the limitation on the water depth to which a suited subject could descend during a training run caused negative impacts on training. A Nitrox (oxygen-enriched air) breathing system would allow the subjects to achieve a greater depth for a greater period of time, thereby allowing enhanced training. The eventual incorporation of an upgraded RMS simulator and a Nitrox breathing system into the NBS in time to support only the October 1993 training runs is discussed below in connection with the recommendations from General Thomas Stafford's HST SM Review Team's second meeting, which occurred February 11-12, 1993.

Numerous hardware and procedure changes were made as a result of these NBS runs. However, some conditions identified as problems in the report were not resolved until very late in the mission flow. The report pointed out the lack of existing capability to support end-to-end timeline verification, but this capability was not realized until the October 1993 NBS runs, after the late installation of the new RMS and the Nitrox systems. The report also stressed the need to finalize tool stowage and tool management. The final tool stowage and tool management major determinations were not made until late August 1993.

An assessment of the HST SM-1 extravehicular activities (EVAs) was conducted by former astronaut Dr. Joe Allen, who issued his report on July 17, 1992. He had been asked by the NASA Office of Space Science and Applications to assess the then-current EVA plan regarding strategy, timeline, and overall feasibility. Among his recommendations, he cautioned NASA to guard against blindly pursuing accommodations for low probability contingencies at the expense of not being ready for the scheduled activities and the more likely contingencies.

He also recommended that the original large ORUs, which were to be replaced, be used for reinstallation practice prior to the installation of the new ORUs. As a result, partial reinsertion of the WF/PC I was performed during STS-61, as was a handling evaluation of the high speed photometer (HSP), which was replaced by the COSTAR. This type of on-orbit assessment proved to be of significant value during the mission.

Mission Director's Recommendation No. 1: EVA tasks requiring precise handling of medium and large masses should be rehearsed on orbit to the extent possible. Tasks involving small, difficult-to-handle objects such as noncaptive screws should also be practiced on orbit.

Dr. Allen also cited the need for the new ORUs to have high fidelity with respect to the old ORUs. This concern is basic to the design of any servicing EVA and is a high priority concern of the NASA EVA community. During the HST SM-1 EVAs, no significant hardware fit problems were encountered. However, a number of previous Space Shuttle EVAs have met with significant difficulties in connecting two pieces of hardware because some "simple detail" was overlooked.

> **Mission Director's Recommendation No. 2: Every effort should be made to completely understand and to be able to duplicate on the ground the configuration of hardware that is on orbit. Methods that can be used to help achieve this capability include detailed records (including photo documentation and accurate engineering drawings, both made of the as-deployed configuration), molds of the interfaces, accurate tooling representing mating interfaces, etc. Such a capability to duplicate on earth what exists in orbit should be considered an initial design requirement for on-orbit hardware.**

> **Mission Director's Recommendation No. 3: The Space Station Program should develop and maintain a detailed three-dimensional computer model of the planned Station configuration similar to Orbiter models maintained in the PLAID and Integrated Graphics Operations and Analysis Laboratory (IGOAL) systems at JSC. The model should be made easy to update as design changes are made. It should be accessible by the Space Station community of designers, customers, and operators. It should be maintained as an as-built model of the station during and after the assembly phase.**

Another area of concern for Dr. Allen, public affairs strategy, was shared by General Thomas Stafford's HST SM Review Team and by the Group Task Force on Satellite Rescue and Repair. Dr. Allen was concerned about the tendency of the national press to ignore successful science, but focus a great deal of attention on failures. To enhance that chances of mission success, and at the same time to strengthen the public perception that NASA was doing all could to succeed, he recommended that NASA select experienced EVA crewmembers for the mission, that ample performance margin be held in management reserve, that an Orbiter having a long on-orbit stay capability be used, and that the EVA crew begin practicing the EVA procedures immediately to increase proficiency, and, therefore, timeline margin. He recommended that the mission tasks be divided into a short list of tasks required to fix the mirror problem; another list of things to do, if time permits, to improve the quality and quantity of new data by installing the new SAs; and yet another lower priority list, including the tasks involving RSUs, ECUs, and GHRS repair kit, just in case there were any time left over. A significant amount of attention was given to formation of a public-affairs plan for HST SM-1. An HST public-affairs team was formed in January 1992. It comprised representatives of the HST Program and Project teams, the NASA centers, the European Space Agency (ESA) and the servicing mission contractors. The team addressed the roles and responsibilities of the various organizations during three phases of the mission: the first included the pre-mission period up to thirty days before launch, the second period was from thirty days before launch until landing, and the third phase was from landing until completion of systems and instrument verification. Biweekly planning sessions were held. Photos, printed materials and videotapes were provided to educators and to the press. A writers' workshop was conducted at the Space Telescope Science Institute in Baltimore, Maryland, and at GSFC in June 1993. A mission operations media workshop was held at JSC in August 1993, in conjunction with the second JIS, allowing the press to see the simulated mission activities. Intensive activities with the press, immediately before and during the mission, ensured wide distribution of information. One of the goals of these workshops and briefings was the indoctrination and education of the numerous reporters who were not accustomed to covering NASA and mission operations.

While the amount of work devoted to the public-affairs plan was extensive, it was not coordinated as well as it should have been. The effort was led by personnel of the NASA Office of Space Science. It was not well coordinated with the Office of Space Flight or the Office of Policy Coordination and International Relations. The overall public-affairs efforts functioned largely independently from mission management, instead of in support of it.

In an attempt to prevent the press from declaring the mission to be a failure if some minor problem were to occur in orbit, NASA devised and presented to the media NASA's own mission success criteria. It clearly divided the EVA tasks into primary tasks, which, if not accomplished, would likely trigger a second servicing mission soon after the first one, and into secondary tasks, which, if not performed, would not cause the mission to be considered a failure. The primary tasks were considered to be those involving SAs, RSU 2, WF/PC, COSTAR, MSS 1, RSU/ECU 3 and SADE.

Mission Director's Recommendation No. 4: For critical and high-interest NASA missions, a thorough public-relations strategic plan should be implemented. It should be well coordinated among all involved NASA offices. A single NASA office should be in charge of the implementation and updating of the plan at all NASA centers and any other key sites (vendor facilities, etc.). Mission success criteria should be generated by mission management early in mission planning and provided to the press by the public-affairs organization(s). A contingency plan of action in response to mission "failure" should be in place and announced before the mission. Information at all levels of detail should be readily available to the press. The mission's importance should not be overstated, and its complexity should not be understated.

The JSC-based HST Review Team, chaired by Richard Fitts, released their findings in the Hubble Space Telescope (HST) Review Team Final Report, dated July

17, 1992. The team had been chartered by the Shuttle Program Office in early June 1992 to perform an independent, non-advocate review of HST SM-1 to:

a. Ensure that adequate and documented plans were in place to evaluate the operations concepts and preliminary design to the point of readiness to enter the standard flow
b. Ensure that Intelsat and Assembly of [Space] Station by EVA Methods (ASEM) lessons learned are applied
c. Review the operating concepts and preliminary design to assess likelihood of mission success and recommend changes as appropriate
d. Determine if all tasks and timelines were workable and if adequate margins existed to ensure success

The Fitts team recommended that the mission be constrained to an Orbiter capable of extended duration missions, specifically one capable of a mission duration of eight planned days, one payload contingency day and two landing contingency days. A similar recommendation was made by the Stafford review team.

Mission Director's Recommendation No. 5: Design all critical missions so that maximum possible mission duration is incorporated at the inception of mission planning. Early development of mission requirements is necessary. If needed to provide adequate margins, an Orbiter with increased-duration modifications should be used for the mission.

The Fitts team also recommended that NASA avoid adding tasks that would require a fourth EVA. (At the time of this review, only three EVAs were planned.) Additional HST problems would later cause an increase to five EVAs, but the extended-duration capabilities of the Orbiter Endeavour accommodated these five EVAs with adequate margin.

The Fitts report also recommended that EVAs continue to be designed to be accomplished by two crewmembers in six hours or less, even though EVAs of seven or more hours are possible. This has been the standard practice in EVA planning and continues to be a good way of ensuring timeline margin.

Mission Director's Recommendation No. 6: To ensure that timeline margin exists for each EVA day, continue to plan tasks for an EVA so that they will take no longer than six hours to complete.

Another Fitts team recommendation was to determine whether certain high priority tasks should be three-crewmember EVAs. Plans were put into place to provide three-crewmember water training runs for the HST crew. However, after analyses of the HST EVA tasks indicated that there would be little value added by a third crewmember for any of the tasks, it was decided to not conduct the training. If three-crewmember capability is determined to be useful for Space Station Assembly and Maintenance EVAs, either scheduled or contingency, those EVAs could be significantly enhanced by hardware modifications.

Mission Director's Recommendation No. 7: Analyze future HST and Space Station EVAs, both scheduled and contingency, to determine whether three-crewmember EVA capability would be desirable. If so, modify the Orbiter air-locks, Shuttle extravehicular mobility units (EMUs), and training facilities to accommodate three-crewmember EVAs. The modifications should include a third air-lock-to-EMU umbilical connection, an EVA radio capable of three-channel operation, and other changes as appropriate.

The Fitts team also recommended human thermal vacuum testing (HTVT) of the flight ORUs, using the assigned flight crew to the extent possible. Due to the large size, the delicacy, and the cleanliness requirements of the HST ORUs, it was not practical to test them in the JSC HTVT runs. The ORUs were tested in non-human thermal vacuum tests. Many of the EVA tools were included in the HTVT. Each of the four HST SM-1 EVA crewmembers had been the test subject in a cold HTVT run within the two years before STS-61. Historically, HTVT has found problems with flight hardware (especially tool) designs that would not have otherwise been discovered before flight. The STS-61 HTVT did uncover some significant hardware problems, which are discussed in connection with the Brasher team presentation on July 13, 1993.

Mission Director's Recommendation No. 8: Flight hardware (including tool) operations and interfaces should be verified as early as possible before flight, in worst-case thermal vacuum conditions to the extent possible.

Mission Director's Recommendation No. 9: EVA crewmembers scheduled to perform EVA tasks in severe thermal conditions should experience those conditions in their flight EMUs (or equivalent) in vacuum chamber testing before their flight.

The Fitts team recommended that NASA consider the practicing of HST SM-1 tasks on prior Shuttle flights, using full scale mockups of HST ORUs. It was decided that there was not sufficient time before the mission to comply with this recommendation.

The Fitts team also recommended that potentially difficult HST tasks be rehearsed on missions before the HST SM-1. EVAs on STS-57 and STS-51 were used to evaluate some of the tools, operations, and Orbiter attitudes planned for use on STS-61 and to evaluate contamination generated by the crew. Insight was gained from these prior missions relating to the hardware and tasks. Far more important, however, was what was learned about the Orbiter bottom-to-sun orientation that had been planned for some of the HST tasks. During the STS-57 EVA, this attitude was found to be extremely cold and uncomfortable by the EVA crewmembers. This result led the EVA and HST communities to pursue and develop a different attitude that kept the EVA astronauts at a comfortable temperature level and still kept sunlight away from the light and heat-sensitive areas of the HST hardware.

Mission Director's Recommendation No. 10: NASA should expand its efforts to evaluate all new hardware, untried procedures, and thermal effects of new Orbiter attitudes, during missions before the missions for which they are required. Development of mission requirements is needed as early as possible to allow time to support these earlier missions. For HST servicing missions, the HST Project organization should develop the plan to exercise tasks and hardware as early as possible. The Space Station Program should closely analyze EVA thermal environments (especially those which will exist while an Orbiter is attached to the Station) to ensure adequate EVA thermal capability.

Another Fitts team recommendation was to investigate modifications to the ORU interface designs to reduce sensitivity to clearance tolerances. Further assessment satisfied the team that the ORU designs were adequate, but the concern remains valid for all EVA hardware interface designs.

Mission Director's Recommendation No. 11: Designs of all hardware having the potential to be attached to or removed from other hardware during EVA should be thoroughly assessed for adequate temperature and vacuum tolerances. Past flight experience and the knowledge base of previous EVA designers should be used in this assessment. See also Mission Director's Recommendation No. 8.

The Fitts team recommended that NASA develop alternate techniques to perform ORU removal and installation that do not rely on the use of the Orbiter's RMS. A significant amount of effort went into the development of and training for the "non-RMS" procedures. It was determined before the STS-61 mission that all the scheduled EVA tasks could be performed during the mission, even without the use of the RMS. Initial assessment of the crew's capability to manually capture and berth the HST without the RMS was considered, but procedures and training for this contingency were not developed. Even though there has never been a complete loss of RMS operability in flight, it is important that this type of contingency planning and training be maintained.

Mission Director's Recommendation No. 12: Critical EVA tasks should be designed so that they can be fully accomplished if there were total loss of the use of the RMS.

Mission Director's Recommendation No. 13: The Space Shuttle Program should thoroughly assess the feasibility of manual capture and berthing of the HST. If determined to be feasible, such procedures should be developed and future HST servicing mission EVA crews should be trained to perform them.

The Fitts team recommended that all critical design tasks be designed so that adequate crew restraints are available. Extensive testing at JSC's Weightless Environment Training Facility (WETF) and Marshall Space Flight Center's (MSFC's) NBS resulted in verified proper placement of crew restraints.

The Fitts team also suggested that NASA implement an expanded EVA integrated simulation template for HST to allow both nominal and malfunction EVA timelines to be exercised by the integrated team. The Space Shuttle Program (SSP), with total support from the HST Project, performed a JIS for each EVA day, during which the mission support team and, on at least two occasions, the SSP and HST management were extensively exposed to nominal and malfunction situations. This training was very effective in improving coordination among the different organizations involved in supporting this mission. See also Mission Director's Recommendations Nos. 21 through 24 and No. 72 and the discussions preceding them.

The Fitts team also recommended the establishment of a single point of contact for EVA training hardware. In a presentation to the Stafford review team on February 12, 1993, Mr. Hal Lambert was named as the single point of contact for all EVA hardware. In a March 29, 1993, memorandum, Mr. Lambert designated Mr. Jim Jaax as the single point of contact. After Mr. Jaax was given a job reassignment, Steve Poulos was named to lead JSC's HST Tool Configuration Control Board (CCB) and to be the single point of contact for EVA hardware beginning April 12, 1993. See Mission Director's Recommendation No. 75.

The Fitts team recommended that, for EVA-intensive flights such as HST, EVA crewmember selection be made as early as possible. The payload commander for STS-61 was named approximately 21 months before flight, and the other three EVA crewmembers 16 months before flight. These early assignments were extremely beneficial in providing flight crew involvement in mission and hardware design earlier than the normal point in the mission flow. Also beneficial to STS-61 was the early involvement of the capsule communicator (Capcom)/Backup EVA crewmember in crew training and EVA task development. The subject of the backup EVA crewmember is discussed in connection with Mission Director's Recommendation No. 64.

Mission Director's Recommendation No. 14: For EVA missions, select the Payload Commander, the EVA crew, and the Capcom as early as possible.

For complex EVA missions it would also be beneficial to perform all planning and requirements milestones earlier in the flow to allow time for proper procedures and hardware development and verification. According to JSC's April 15, 1994, edition of "Flight Production Generic Templates," the approximate timing for some key mission events follows.

EVENT	MONTHS BEFORE FLIGHT
Flight Definition and Requirements Directive (FDRD) Baselining	15.5
Cargo Integration Review (CIR)	11.5
Flight Planning and Stowage Review (FPSR)	8.5
Flight Operations Review (FOR)	3

For STS-61 the approximate timing follows.

EVENT	MONTHS BEFORE FLIGHT
FDRD	17
CIR	11
FPSR	8.5
FOR	4

Mission Director's Recommendation No. 15: For complex EVA missions, perform flight production milestones earlier than in the standard template. For the second HST servicing mission, consider the following template.

EVENT	MONTHS BEFORE FLIGHT
Selection of Payload Commander and EVA crew*	24
Baselining of Flight Definition Requirements Directive	20
Cargo Integration Review	15
Flight Planning and Stowage Review	11
Flight Operations Review	4

Other mission milestones should be moved earlier proportionately.

*** For missions requiring close coordination among the commander, pilot, RMS operator(s) and EVA crew, consideration should be given to selecting the entire crew at this time.**

The Fitts team recommended that to maximize the likelihood of mission success, NASA should consider EVA crew selection criteria such as EVA experience or demonstrated EVA proficiency. While it is probably not essential that all EVA crewmembers for critical EVAs have previous on-orbit EVA experience, it is important that the Payload Commander and others involved in the mission design and planning be experienced. Because of the complex logistical and safety aspects involved in EVA, it is also beneficial to have a Commander who has flown an EVA mission and an EVA-experienced Capcom. Space Station assembly will be more EVA-intensive than any previous space mission. The corps of EVA-experienced crewmembers should be expanded to the maximum extent possible before Station assembly.

Mission Director's Recommendation No. 16: Use EVA-experienced flight crewmembers, preferably the Payload Commander and other

EVA crewmember(s) who are assigned to the mission, to help develop and evaluate critical EVA hardware, tasks, and procedures.

Mission Director's Recommendation No. 17: To the extent possible, assign an EVA-flight-experienced Commander and Capcom to critical EVA missions.

Mission Director's Recommendation No. 18: To increase margins for the success of the Space Station assembly, determine the tasks required for assembly and the number of crewmembers required to perform them. Use EVAs on prior Space Shuttle missions to practice those tasks and to provide EVA experience to as many different astronauts as possible.

The Fitts team also recommended that EMU interchangeability be considered as a criterion for crew selection. This practice would increase the flight crew's capability to substitute a backup EMU if any primary EMU were to fail to function properly.

A similarly important backup capability would be the capability to substitute a backup EVA crewmember in flight if one of the primary crewmembers becomes unable to perform the EVA.

Mission Director's Recommendation No. 19: For critical EVA missions, select EVA crewmembers so that the required EVA tasks can still be fully accomplished if either a crewmember or an EMU becomes unable to support an EVA.

The Fitts team recommended that the then-current design of JSC's EVA hardware be reviewed with respect to the HST task requirements, and to implement improvements where needed to increase the chances for mission success. See Mission Director's Recommendations No. 8, No. 10, No. 11, No. 74, and No. 77.

Another Fitts team recommendation was a human factors assessment of all EVA system elements to identify changes necessary to improve the overall operational effectiveness for future EVA flights. A human factors assessment was not separately conducted for HST SM-1. The improvements made to the EVA design based on human factors were by-products of the training template activities. Future EVAs, and especially Space Station EVAs, would be well served by a structured human factors assessment process. This task might appropriately be assigned to JSC's newly formed EVA and Crew Equipment Project Office.

Mission Director's Recommendation No. 20: Establish a formal human factors assessment effort to identify and facilitate improvements to generic EVA capabilities and hardware and to enhance EVA procedures as required for specific EVA tasks. This

responsibility might best be assigned to the newly formed EVA and Crew Equipment Project Office.

On July 17, 1992, the Flight Definition and Requirements Directive (FDRD) was updated by Program Requirements Control Board Directive (PRCBD) No. S042061, to include the STS-61 mission. This PRCBD designated the launch date to be December 2, 1993, and the mission duration to be eight days. It also designated the use of a fifth cryotank set in OV-105 for the mission. This configuration was expected to provide capacity for four contingency days. This mission duration represented an increase of two contingency days over the previous plans (eight planned days plus two landing contingency days [8+2]) and an increase of one contingency day over the minimum duration recommended by the Fitts team (eight planned days plus one payload contingency day, plus two landing contingency days [8+1+2]). The IMAX cargo bay camera (ICBC) and the in-cabin IMAX camera were also placed on the flight by this directive.

On July 23, 1992, the first HST Flight Techniques Panel meeting was held.

On August 8, 1992, the Program Review Team (PRT) for HST SM-1, chaired by Dr. Michael Greenfield, released the report of its first of four reviews. The PRT had been chartered by NASA Acting Deputy Administrator on July 14, 1992, to provide the program and project offices with high-level, independent assessment of the thoroughness of the development, integration, and verification processes and to ensure that the multicenter HST servicing team was addressing problems satisfactorily. In this first report, the PRT recommended that the HST Project Office develop specific decision-making guidelines and define the management process to be in place during the mission, and that these guidelines and this process be exercised in JISs. Prior to the JISs, GSFC mission support personnel participated in a number of GSFC-only simulations, giving them a considerable amount of experience with the decision and information flow among their own organizations. This early practice contributed significantly to the efficiency of the more expansive JISs and should be continued for future servicing missions. It should also be considered for implementation within the Space Station Program. The large number of JISs and the involvement of management personnel in them resulted in a well prepared and coordinated team. However, the training objectives of the JISs and the areas in need of improvement were not well documented in post-JIS reports to the participants.

Mission Director's Recommendation No. 21: Continue the practice of having all mission support personnel, including management and especially customer management, participate in joint integrated simulations (JISs) for critical missions. JISs for scheduled EVAs should be conducted with EVA crewmembers in underwater training facilities, unless facility or mock-up limitations prevent the crew from performing realistic activities.

Mission Director's Recommendation No. 22: For critical missions, the Mission Operations Directorate should develop more clearly defined and detailed training objectives for the JISs for flight controllers, flight directors, and mission and customer management. Post-JIS reports should be distributed to the JIS participants detailing these objectives and how well they were achieved. Corrective actions should be assigned and lessons learned should be formulated and distributed.

Mission Director's Recommendation No. 23: For HST servicing missions, continue the practice of conducting HST Project internal simulations. They should be well structured and the results should be well documented.

Mission Director's Recommendation No. 24: The Space Station Program should assess the benefits of performing internal simulations prior to the JISs for Space Station assembly. If determined to be of value, they should be well structured, with clear training objectives, and the results should be documented and distributed to the participants. Objectives should include the definition and exercising of the relationship between the Launch Package Teams and the Flight Control Team during both nominal and contingency operations.

The PRT also recommended that GSFC's servicing mission manager, the systems management team, and the supporting HST and Space Support Equipment (SSE) documentation all be located at JSC during the mission. It is extremely important to have quick access to all technical information about a payload or other hardware to help support trouble-shooting efforts. The system used for photographic image retrieval during STS-61 was not well indexed or conducive to rapid image retrieval.

Mission Director's Recommendation No. 25: The Mission Operations Directorate should assess the methods used to access payload technical data, drawings, and photographs during the STS-61 simulations and during the STS-61 mission. Corrective actions should be implemented to eliminate all identified problems. Work should continue on improvement of storage and retrieval efficiencies. See Mission Director's Recommendations No. 41 and No. 71.

The PRT recommended that the Payload Integration Plan (PIP) be completed as soon as possible. For complex missions, it is important that all mission requirements documentation be released earlier than for a standard mission. This accelerated documentation schedule would allow more time for the mission planners and designers to develop and perfect hardware, techniques, and procedures. See Mission Director's Recommendation No. 15.

The PRT also recommended the development of a top-level fault tree to address issues at the systems level for individual instruments. GSFC performed an extraordinary amount of contingency analysis and planning (including a top-level fault-tree analysis), which, along with their extensive internal simulations, allowed mission support personnel to respond quickly and properly to complicated problems. Such analysis and planning would be beneficial also to the Space Station Program.

Mission Director's Recommendation No. 26: The Space Station Program should consider the development of a top-level fault-tree analysis.

The PRT advised the HST project to coordinate with the Government Furnished Equipment (GFE) boards to establish consistent certification criteria for all GSFC-developed tools before proceeding with tool development and assembly. The goal of establishing consistent tool certification criteria has not yet been achieved. There continue to be philosophical differences in the ways different centers certify hardware. In some cases there are differences in the ways two very similar hardware items, both belonging to JSC organizations, are certified. Payload hardware, GFE, contractor-furnished equipment (CFE), payload integration nominal cost hardware (PINCH), and different NASA centers all have their own distinct certification approval processes. Inconsistencies in certification requirements are, at best, wasteful of program resources, and, at worst, dangerous. Certification of EVA hardware is further discussed below in connection with the Brasher team's July 13, 1993, presentation. See Mission Director's Recommendation No. 75.

The PRT report also recommended that the HST Project and JSC develop a common position regarding the types of crew training events and operational assessments that are suitable to conduct using GSFC's High-Fidelity Mechanical Simulator (HFMS). The hardware interface evaluations, verifications, and training conducted for STS-61 using the HFMS were extremely valuable. The HST EVA Servicing Mission Support Plan (EVASP [#8266, LMSC/P015686]) was developed to define testing activities using the HFMS, among other facilities. It would be useful to have a similar training plan to define and coordinate all training requirements for future HST servicing missions.

Mission Director's Recommendation No. 27: Consider the implementation of an overall training facilities requirements control document for future HST servicing missions. It should define, as early as possible, the testing and training to be done at the various training facilities (vendors, High Fidelity Mechanical Simulator [HFMS], KSC, WETF, Neutral Buoyancy Simulator [NBS], et al.).

The PRT also recommended that all sources of crew-induced contamination be identified and resulting operational constraints be developed and documented. A number of special procedures were implemented for STS-61 to help prevent contamination of HST hardware. Tools and crew aids received special cleaning. "Highly sensitive" cleaning procedures were invoked for items in the Orbiter payload bay, crew cabin and air lock. The cabin air cleaner and a replacement payload bay liner were flown. A special bake-out of the EMU glove new thermal micrometeoroid garments was performed to reduce the chance of HST contamination from out-gassing of the materials during the EVAs. After the payload bay was contaminated by sand and debris at Launch Pad A, the payload bay received another special cleaning before the payload was installed. (The contamination of the payload bay and the Payload Change-out Room [PCR] is discussed below in connection with Dr. Greenfield's July 28, 1993, report [See Mission Director's Recommendation No. 80.] and in the entry for October 30, 1993.) The Space Shuttle and payload were also transported to Launch Pad B, from which they were launched. On the basis of the results of post-STS-61 HST testing and operations, it appears that no significant contamination was introduced into the telescope during the EVAs. However, some concerns still exist about the chances of contaminating HST and other sensitive payloads during future missions. The crew observed that it was common for paint to chip from handrails when in contact with tether hooks. Pieces of multi-layer insulation (MLI) and labels were seen floating from their original locations. A GHRS sensor indicated a pressure change, and, therefore, the introduction of gas into the HST after the firing of Orbiter reaction control jets. IMAX film made during the mission revealed apparently metallic debris floating out of the payload bay near the HST.

Mission Director's Recommendation No. 28: The Space Shuttle Program should perform a complete assessment of the results of the HST SM-1 mission relating to potential sources of contamination. The results of this assessment should then be provided to all payload owners, including the HST Project, and the Space Station Program. Review crew comments, indications of pressure spikes inside the HST, and films and videotape made during the mission (including IMAX film of EVAs and videotapes made during the opening of the payload bay doors).

Mission Director's Recommendation No. 29: The HST Project should examine returned components removed from HST for indications of previous contamination and of material deterioration that would indicate the potential for generation of contamination by similar materials still on orbit. These results should be incorporated into the Space Shuttle Program's assessment discussed in Mission Director's Recommendation No. 28.

Mission Director's Recommendation No. 30: The Space Shuttle Program should develop and publish data indicating temperature ranges and locations within the payload bay that should be avoided by payloads sensitive to vapor or condensation of Orbiter supply water, waste water, flash evaporator system water, reaction control system (RCS) jet combustion products, and leaking RCS propellants.

The PRT recommended that the HST Project produce and provide for use in training and during the mission a drawing indicating areas of the HST that should not be touched by EVA crewmembers. Such a drawing was provided to the EVA training personnel who then incorporated the information into the crew's training sessions.

Mission Director's Recommendation No. 31: Continue to provide to EVA astronauts clear and detailed training in what, if any, items in or near the EVA work areas should not be touched by them. These items should be represented by mock-ups during training to ensure that EVA procedures can be accomplished without contact with the "no-touch" zones.

The PRT assessed the verification process used to ensure that the COSTAR would fit into the high-speed photometer (HSP) bay, both structurally, and optically. The team determined that the methods used, which included the use of the Axial Bay Simulator (located in the HFMS), were adequate. To ensure that future replacement instruments can be dimensionally verified preflight, it is essential that strict configuration control be maintained on ground sizing fixtures.

Mission Director's Recommendation No. 32: For as long as the HST is in service, the HST Project should use strict configuration control to maintain the fidelity of their High-Fidelity Mechanical Simulator.

The PRT recommended that accurate mock-ups of all scientific instrument critical clearance areas be made available to the assigned flight crew during their training. It is essential that crew training be conducted with accurate representations of the hardware that will be used in flight.

Mission Director's Recommendation No. 33: For both the Space Shuttle and the Space Station Programs, continue and expand the efforts to make training mock-ups that are dimensionally as flight-like as possible. Be alert to any differences between training and flight hardware and incorporate the necessary precautions into the training plan to avoid negative training. Take precautions to prevent damage from handling, shipping, etc., and deterioration from corrosion, inadequate maintenance, etc.

The PRT recommended that materials and training should be provided to repair any multi-layer insulation (MLI) or tape that may be pulled loose during any scientific instrument (SI) removal. No MLI problem was encountered during the SI operations during the mission. With the increasing age of the HST MLI and the increasing likelihood of micrometeoroid and debris impacts to the telescope, there is a significant chance that MLI repair capability will be needed during future HST servicing missions. The potential need for such a repair capability was emphasized during the mission when it was visually discovered that a particle had perforated the HST high gain antenna dish.

Mission Director's Recommendation No. 34: Develop and verify the adequacy of a multi-layer insulation (MLI) repair kit for future HST servicing missions. It should enable EVA astronauts to repair the black MLI inside the telescope cavities and the MLI external to the telescope and to repair light leaks resulting either from micrometeoroid or other damage to the telescope or from poorly fitting doors or light seals.

The PRT was interested in methods of verification that light leaks were not present in the body of the HST at the completion of the mission. It was determined that there was no practical, simple test that could be performed during the STS-61 mission. Such a test would allow any needed repairs to be made without requiring another servicing mission.

Mission Director's Recommendation No. 35: Reassess the feasibility of developing a method for detecting light leaks in the HST during future servicing missions.

The PRT was also concerned about the possibility that last-minute changes to flight or ground documentation made necessary by changes in hardware or procedures might not be made in time if they are simply submitted through the normal approval processes. The team recommended that the HST Project take an active role in working with the JSC operations community to ensure that all needed changes are made. The HST Project did work closely with the JSC operations personnel to ensure that there were very few surprises found during the mission.

The Problem Review Team Report No. 1 also addressed the issue of early crew designation, which is discussed in connection with the Fitts team recommendations and in Mission Director's Recommendations No. 14 and No. 15.

The Flight Requirements Document was approved on August 14, 1992. It established the mission's requirement to support three planned EVAs, two payload contingency EVAs, and one Orbiter contingency EVA. This six-EVA capability was the minimum capability recommended in the July 17, 1992, report of the Fitts team.

On August 14, 1992, the group that was established at JSC to investigate the problems encountered during the Intelsat capture EVAs on STS-49 released a memorandum documenting the results of their assessment (JSC, GA-92-064). Some of their recommendations had applicability to the HST SM-1.

The Intelsat group recommended that sufficient engineering analysis be performed before commitment to an operations concept. While the overall concept for HST servicing had been established years earlier, some innovative mission development and training methods were employed for STS-61. Virtual reality techniques were used in the development of some of the RMS positions and procedures and in the verification of others. In addition, some air-bearing devices used in the Apollo program were employed in a new way to provide training for mass handling.

The Intelsat group also recommended that the limitations of simulation methods used for critical design verifications and crew training activities be verified, documented, and regularly reinforced to the personnel involved in these activities. For STS-61, adequate precaution was taken to make the flight crew aware of which aspects of their training were flight-like, and which were unique to the training method being employed. An example is the demonstration of the actual flight ORUs to the crew fairly early in the training schedule, so that they would know how the training mockups differed from the flight items. The validity of the STS-61 simulation methods was independently assessed by the EVA Peer Review Team, chartered by the STS-61 Mission Director and led by Col. Jerry Ross. This team found that the methods provided valuable training and that limitations were adequately communicated to the crew. See Mission Director's Recommendation No. 55.

The Intelsat group recommended the development of a project management plan that defines roles and responsibilities, tasks, and analyses for hardware development, operations, and training for missions with high complexity and risk. GSFC released the first version of their HST First Servicing Mission Management Plan in October 1992. It was revised significantly in September 1993. The Space Shuttle Program published their Space Shuttle Program Project Plan for STS-61 in April 1993.

Mission Director's Recommendation No. 36: For complex missions a management plan should be developed early in the planning flow. The development and execution of the plan should be coordinated among the various elements of the mission team.

The Intelsat group also recommended the use of peer review to validate operations concepts and the design before committing to new high-complexity missions. Although they were not formed solely in response to this recommendation, peer review groups did make significant contributions to the success of the HST SM-1. The Tool Review Team, headed by Mr. Warren Brasher, helped to implement corrective actions for the tool problems discovered during human thermal vacuum testing and helped to enhance the effectiveness of the STS-61 tool certification process. The recommendations of this team are discussed below in connection with the team's July 13, 1993, presentation of the results of their investigation. Another team, led by Col. Jerry Ross, enhanced STS-61 EVA efficiency with their recommendations for revising EVA procedures and tool stowage locations. Such review activities can add significant value to the preparation for a critical mission, but care should be taken to prevent negative impacts to the mission team activities caused by the review team's need to become educated on mission details.

Mission Director's Recommendation No. 37: For critical missions, including HST servicing and Space Station assembly and maintenance missions, a multidisciplinary team should be established to provide a thorough and comprehensive independent assessment of flight readiness. The team should identify areas of potential risk and make recommendations of appropriate actions to enhance mission success.

The team must possess a relevant experience base. The team leader and panel chairs must possess broad program experience. The core team members should be selected for applicable technical background and mission experience, including EVA experience from a similar mission or membership in a previous similar assessment effort. The team should identify and use a large pool of independent experts, both internal and external to NASA in all key areas. It should plan for sub-panel assessment activities to be led or coordinated by a core member of the team.

There should be established a good understanding of, and agreement on, the team's objectives, approach, and schedule, among the team, mission management, payload (e.g., Space Station) and Space Shuttle program management, and contractors. The team should establish close and on-going interaction with the mission team management. A Mission Director, if assigned, should be the overall focal point for interface and should establish the process for contractor interface. The team should establish a formal process for working with the mission team, using an informal working relationship but maintaining a formal response and action process.

The team's effort should begin with payload hardware design reviews and continue until launch. The team should develop a plan of action and milestones for team effort based on established funding. It should optimize its level of effort for available funding and carefully track costs. The team should strive to minimize disruption by scheduling their reviews in coordination with established events and milestones for mission hardware, for Space

> Shuttle Program (SSP) mission preparation milestones, and center and Headquarters reviews. Their readiness review effort should be expanded for critical design review and test readiness reviews. A small sub-panel of technical experts should participate in hardware reviews. Their expertise should include EVA experience as appropriate. Their effort should focus on design, testing, interfaces, fit, and processing. The team's effort should again be expanded for mission planning and mission preparation activities. The team should influence mission operation plans and contingencies.
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> The team should make extensive use of lessons learned data bases from related activities. It should make extensive use of available data and individual team members should conduct reviews prior to the collective assessment effort in order to minimize travel.
>
> It should conduct an independent assessment of the flight worthiness of the design, the fabrication and testing, and the integration and preparation of the mission hardware, software, and supporting systems. The team's review should assess exceptions to performance and build norms, analyze waivers and deviations, review failures and their resolutions, and assess payload hardware-to-Orbiter interfaces. The team should also review preflight planning activities, training and simulation plans, and mission plans. The mission management should be reviewed regarding structure, processes, responsiveness, and effectiveness. The team should assess closure of anomalies and management response to review team issues and recommendations.

The Intelsat review group also stressed the importance of enhancing and demonstrating EVA technologies and capabilities to the maximum practical extent, including demonstration of complex Space Station EVA requirements. See Mission Director's Recommendations No. 1, No. 7, No. 10, No. 13, No. 18, No. 20, No. 45, No. 51, No. 84, and No. 85.

In August 1992, another series of NBS tests was conducted. The nineteen tests, including thirteen runs with Dr. Story Musgrave and Lt. Col. Thomas Akers as subjects, performed procedures verification for non-RMS removal/installation of WF/PC (using WF/PC installation tool [WIT]), HSP/COSTAR, RSUs, SAs, ECUs and GHRS switching box; testing of contingency procedures for the high-gain antenna (HGA), SA primary deployment mechanism (PDM) and secondary deployment mechanism (SDM), WF/PC scientific instrument protective enclosure (SIPE) latches, axial SIPE safety bar, WF/PC and COSTAR rapid safing, and solar array drive assembly (SADA) clamp; verification of nominal RMS procedures for WF/PC (with and without WIT) and integrated DF-224 and coprocessor; and testing of developmental procedures for RSU, HGA retraction, and low gain antenna (LGA) cover.

During these runs the crew preferred the use of foot restraints for most tasks, in spite of the extra time required for set-up. (Minimization of the performance of free-floating tasks was also one of the lessons learned from the STS-49 ASEM EVA.) After these tests the use of power tools was considered to be the baseline method for bolt installation and removal. The crew also preferred that nominal change-out of the WF/PC should be performed without using the WIT. A number of Jet Propulsion Laboratory (JPL) and GSFC personnel believed that the WIT would allow safer, more secure handling of the WF/PC by the crew. It was later decided in the Flight Techniques Panel meeting on December 11, 1992, to not use the WIT for the task. It was also pointed out after these NBS runs that the management of tools, crew aids, and tethers needed continual review.

On August 28, 1992, Dr. Jeffrey Hoffman, Dr. Kathryn Thornton and Lt. Col. Tom Akers were announced as the remaining three EVA crewmembers for STS-61. Earlier assignment of the entire EVA crew would have allowed greater crew participation in the March and August 1992 NBS development runs, and therefore greater crew involvement in the hardware design and EVA procedures development. See Mission Director's Recommendations No. 14 and No. 15.

On September 10, 1992, General Thomas Stafford convened at GSFC the first meeting of his HST SM Review Team, which he had formed at the request of the NASA Associate Administrator for Space Flight. The team was tasked to review all aspects of the mission plans, "including the adequacy of servicing and repair hardware and preflight planning and training." On September 18, 1992, the quick-look report of their assessment was released.

Stafford's team recommended the establishment of a mission manager. On December 15, 1992, the Associate Administrator for Space Flight named Mr. Randy Brinkley as Mission Director, who served to "coordinate the efforts of the team working to safely and successfully accomplish the HST Servicing Mission." The Mission Director is discussed below in connection with Mission Director's Recommendation No. 48. On February 18, 1993, the Space Shuttle Program named Mr. Hal Lambert as Mission Manager, who was to provide Shuttle management overview and resolution of issues associated with the mission. The Mission Manager is discussed below in connection with the November 25, 1992, mission status telecon.

Stafford's team also recommended the testing in a thermal vacuum facility of tolerances and especially the mechanical interfaces of mission tools, equipment, replacement units, and scientific units. See Mission Director's Recommendation No. 8.

Stafford's team recommended the upgrading of the RMS simulator at MSFC's NBS. By the time of the Stafford team's second meeting, which occurred February 11-12, 1993, no apparent progress had been made toward this upgrade. This subject is discussed below in connection with the recommendations from that February meeting.

Stafford's team recommended that as much on-orbit testing as possible be performed on the HST while the Orbiter was still nearby. They also specifically recommended that the aperture door (AD) be opened while the Orbiter was still within reach. Extensive work, some performed before this recommendation was made, went into the development and execution of tests performed during or after each EVA to verify that replacement components were electrically alive and that no noticeable problems were caused by the EVA activities. These tests were very effective methods of indicating that the EVA activities were properly performed. The issue of when to open the AD had been in work for both the HST deployment mission (STS-31) and the STS-61 mission. When analysis indicated the risk of contamination to HST to be acceptably low, it was also decided to open the AD while the HST was still grappled by the Orbiter's RMS.

Stafford's team suggested that, given the greater inherent risk of a night landing, NASA verify that a night launch was essential to the success of the mission. Because of the limited number of days each month in which both potential launch-abort landings and the nominal end-of-mission landing would occur in daylight, it was decided not to make daylight landing a mission requirement. Development of a night scene for the portable in-flight landing operations trainer (PILOT) was accelerated to support STS-61 in-flight training. The commander and pilot for STS-61 both received extensive night-landing training in the Shuttle training aircraft and the shuttle mission simulator. However, there are no established requirements for training for night landings.

> **Mission Director's Recommendation No. 38: Establish nighttime Shuttle training aircraft (STA) training requirements for the commanders and pilots of all Space Shuttle missions. This is especially critical for missions scheduled to land at night and for ground-up rendezvous missions, which have the potential for landing at night, depending on when they are launched. Establish requirements for demonstrated minimum performance levels for night landings.**

Stafford's team recommended that HST EVA priorities be defined as soon as possible. Given the dynamic nature of the condition of HST as component degradation continued, it was understandable that EVA task priorities would change fairly late in the mission development. However, this situation is not conducive to efficient mission preparation. Requirements should still be established early and updated as required.

> **Mission Director's Recommendation No. 39: To help ensure efficient and successful planning and execution of complex EVA missions, it**

is important that EVA task priorities be established as early as possible, preferably well before the standard time of publication of the Payload Integration Plan, and before the occurrence of the Cargo Integration Review.

Stafford's team also recommended that, given the experience of the STS-61 EVA crew, NASA consider waiving the requirement against performing EVAs before the fourth day of the mission. After thorough review of this suggestion, it was decided to keep the first EVA scheduled for the fourth day. An earlier EVA day would have seriously compressed the timeline for the large amount of preparatory activities. It would also have increased the risk of something being left undone and of some crewmembers still being under the effects of space adaptation syndrome (SAS) when scheduled to perform an EVA. For future critical missions, the scheduling of an EVA before flight day four should be considered only for experienced crews with low risk of SAS, and after a thorough analysis of pre-EVA activities and timelines.

Mission Director's Recommendation No. 40: Scheduling of critical EVAs before flight day four should be done only for missions whose critical crewmembers have an established history of being free of space adaptation syndrome symptoms by the flight day of the EVA, and should be done only with the concurrence of the crew and the flight surgeon, based on a thorough analysis of pre-EVA activities and timelines.

The Stafford team cautioned NASA against scheduling secondary objectives to be accomplished prior to the primary ones. While this concept is basic to all Shuttle mission planning, because of the changing priority of the tasks of HST SM-1, it was a matter of consideration until fairly late in the mission planning. The flight plan was made according to this philosophy, except where the time predicted to perform the task having the next greatest priority exceeded the time remaining in the EVA. In these cases lessor priority tasks were scheduled. The most noticeable example of this type of exception is the SA change-out, which, although it was the top priority task, was performed during EVA 2, because it could not be performed in a single EVA unless some preparatory work had been performed first.

The Stafford team cautioned NASA to not relay excessively optimistic expectations to the news media and the public. The STS-61 public affairs activities are discussed above in connection with the Dr. Allen recommendations of July 17, 1992. See Mission Director's Recommendation No. 4.

Mr. John Young released memorandum no. AC5-92-37 on September 17, 1992. It raised a number of issues related to STS-61 and future missions. He suggested the thorough review of photographs taken of HST both at the place of manufacture and on orbit, to look for any unexpected conditions. While thousands of photographs have been taken of HST and its components, it is not a simple matter to organize them in a rapidly retrievable manner. The storage and retrieval systems used during STS-61 did not have easily usable or complete indexes.

> **Mission Director's Recommendation No. 41: For the future HST servicing missions, as well as for all other critical EVA missions, including Space Station assembly and maintenance missions, it is important to develop comprehensive collections of photography (including videotape and digital imagery) of the flight hardware, organized in a manner that will support timely analysis and troubleshooting. To the extent possible, plan to make a complete photographic record of the prelaunch and on-orbit configurations of deployed hardware to help ensure that future mission planning will be based on accurate data. Imagery data should be maintained in a readily accessible, rapid-retrieval system. See Mission Director's Recommendations No. 25 and No. 71.**

Mr. Young stated that the crew scheduling constraints found in Appendix K of the Space Shuttle Crew Procedures Management Plan are often waived during a mission to increase the chances of mission success. In the planning of HST SM-1, the question arose whether a crewmember could perform EVAs on consecutive days, without approval of the mission management team (MMT). Some mission support personnel believed that the flight director has the authority to waive the constraint. Others believed that a decision from the MMT is required.

> **Mission Director's Recommendation No. 42: To provide clearer decision-making guidelines for matters involving crew activity constraints, the authority to waive constraints in Appendix K of the Space Shuttle Crew Procedures Management Plan should be clearly defined.**

Mr. Young cautioned that, because of the high criticality of the EVA power tools, the battery and power tool provisions should be "overkilled." During STS-51, a power ratchet tool battery failed to provide power for as long at it was expected to. During STS-61, an HST power tool failed. In both of these cases, sufficient spares were flown to allow completion of the scheduled tasks. Since such failures of EVA hardware are not uncommon, it is necessary to have ample backups for tools and batteries.

> **Mission Director's Recommendation No. 43: For critical EVA tools and batteries, ensure that ample in-flight backups are available. If the use of power tools is essential to the completion of required tasks, fly enough tools and batteries to accommodate multiple failures of each.**

Mission Director's Recommendation No. 44: Review the performance of the batteries used during the STS-61 EVAs. Assess the adequacy of the strategy used to manifest the types and quantities of the batteries that were flown. Compare the STS-61 battery plan to other techniques and technologies, including in-flight recharging, and other types of batteries.

Mr. Young recommended an investigation into the concept of self-rigidizing tethers attached to the waist area of the EMU to provide the capability to restrain the EVA crewmember in less time than it would take to set up a foot restraint. This concept was not developed for STS-61. Such an attachment device would likely be useful to the Space Station Program, where the potential exists for EVAs to be performed in locations not accessible from foot restraints.

Mission Director's Recommendation No. 45: Investigate alternatives or improvements to the present foot restraint concept, to enable an EVA crewmember to be secured at worksites for which the present foot restraints are not satisfactory.

On September 29, 1992, the Group Task Force on Satellite Rescue and Repair released their report in Washington, D. C. The task force, part of the NASA Advisory Council, had been established by the NASA Administrator on May 14, 1992, "to review policies, pricing, and implementation for undertaking unanticipated satellite rescue and repair missions utilizing the Space Shuttle." The task force was chaired by Dr. Eugene Covert, Head of the Department of Aeronautics and Astronautics of the Massachusetts Institute of Technology. The report contains six recommendations related to the implementation of rescue and repair missions.

The first recommendation is that NASA should continue to ensure that safety requirements are met for all satellite rescue and repair missions. The NASA safety processes for an EVA mission are complex and disjointed. Hardware provided by the payload customer is subjected to review by the Payload Safety Review Panel (PSRP). In-flight operations that serve as controls to safety hazards are submitted by the PSRP to the Mission Operations Directorate's (MOD's) Flight Techniques Panel(s) for assessment of EVA safety. MOD is tasked with the responsibility for overall operational safety verification, which it performs as part of its Flight Techniques Panel process. A majority of the Space Shuttle Program's (SSP's) EVA hardware is classified as flight crew equipment (FCE), a subset of the SSP's government-furnished equipment (GFE). EVA equipment that is built especially for a specific payload is usually classified as payload GFE hardware. Although these two different types of GFE items are controlled by two different configuration control boards (CCBs), they are both subjected to the same GFE safety approval process, which is separate and distinct from the PSRP. Some EVA items (such as some tools) that are flown on every mission for contingency purposes are classified as contractor-furnished equipment (CFE). CFE is reviewed under yet another set of safety requirements. Some Orbiter equipment that is incorporated to accommodate a specific payload is classified as payload integration nominal cost hardware (PINCH) and is approved through a process different from the CFE process. For each mission an integrated cargo hazard assessment (ICHA) is performed, using a standard checklist of generic hazards to screen for hazards caused by any of the payloads on a mission due to their proximity to or interaction with Orbiter systems, other payloads, or personnel.

For each mission, a Prelaunch Assessment Review (PAR) is conducted by the Safety, Reliability, Quality Assurance, and Mission Assurance personnel of the various NASA centers and NASA Headquarters. At the PAR are heard descriptions and assessments of any significant known problems that might affect the mission under review. The Systems Safety Review Panel (SSRP) at JSC, at its discretion, can assess any aspect of mission hardware, preparation, or procedures for compliance with safety requirements. Because both the PAR and the SSRP are *review* bodies, their assessments occur close to the launch date, and therefore usually cannot proactively affect the mission under review.

Typically, there is no one entity that actively controls or coordinates the various safety processes during the preparation for a Space Shuttle mission. For HST SM-1, there was no discernible comprehensive mission assurance effort.

Mission Director's Recommendation No. 46: For each NASA human space mission, designate a single point of contact who is directly responsible for coordinating the entire safety and mission assurance effort for the mission (including hardware, systems, and operations).

Mission Director's Recommendation No. 47: NASA should develop a single process that is responsible for all aspects of EVA safety and mission assurance (S&MA). This process should assess the integrated EVA-related S&MA aspects of flight crew equipment, other government-furnished equipment, payload-related hardware, and EVA, Orbiter, and payload operations.

The second task force recommendation was that mission managers should be assigned upon acceptance of a mission and that the mission manager should be responsible for all aspects of preflight mission execution. A mission manager was named within the Space Shuttle Program to manage the Level III (project level) aspects of the mission, but not "all aspects." The STS-61 Mission Director was designated by the Associate Administrator for Space Flight to "coordinate the efforts of the team," but was not given full responsibility for the team. For future significant NASA missions, a Mission Director should be appointed and be given clearly defined roles and responsibilities.

Mission Director's Recommendation No. 48: A mission director should be appointed for future HST servicing missions and other highly complex space flights designated by the NASA Administrator. The mission director should be responsible for the management direction and oversight of the integration and flight preparation process and accomplishment of the mission. The mission director's responsibilities should include oversight of the mission training and concurrence in the determination of the flight readiness of the flight crew, the integrated operations team, the customer management team, and the mission management personnel. The mission director should provide concurrence in the date and time of launch, and the launch window. The mission director should also concur in the mission goals, objectives, priorities, and policies. The mission director should participate and concur in the selection of the crew. The mission director should be responsible for the proper coordination among the various NASA offices, NASA centers, NASA program managers, and persons, groups, and organizations external to NASA who have a responsibility for the safe and successful execution of the mission. The mission director should establish special committees and/or assessment teams, as required, to assess the readiness of the STS and cargo to support mission requirements. The mission director should have final approval authority of the cargo mix, including secondary payloads, detailed test objectives (DTOs), and detailed supplementary objectives (DSOs). The mission director should be responsible for the resolution of key issues involving any aspect of the mission. The mission director should co-chair the Mission Management Team (MMT). The mission director should be responsible for ensuring that the Space Transportation System (STS) and cargo comply with all safety requirements. The mission director should be responsible for mission assurance and flight readiness of the STS and cargo, and provide concurrence in resolutions of payload or Orbiter anomalies that have a potential impact on mission success. The mission director should be a signatory on certificates of flight readiness that pertain to the specific flight for which the director has responsibility. The mission director should provide concurrence in the approval or disapproval of flight specific waivers. The mission director should represent and report directly to the Associate Administrator for Space Flight.

The third recommendation of the group task force was that mission integrated training is essential for all aspects of Shuttle training. See Mission Director's Recommendations Nos. 21-24, No. 59, and No. 72.

The fourth recommendation was that NASA should adequately communicate the inherent complexity of rescue missions to the public. The STS-61 public affairs activities are discussed above in connection with the Dr. Allen recommendations of July 17, 1992. See Mission Director's Recommendation No. 4.

The fifth recommendation of the task force was that NASA should commit to the maximum use of individuals with previous experience (both internal and external to NASA) and past lessons learned to help ensure mission safety and success. For HST SM-1, significant contributions were made by EVA-experienced astronauts directly involved in the mission, including the flight crew themselves, and by astronauts and former astronauts participating in EVA procedure reviews, most notably the Independent EVA Assessment team established by the HST Mission Director and led by Col. Jerry Ross. NASA also made significant use of EVA planning and training personnel who had extensive experience on previous EVA missions. Their use of proven, and, in some cases, innovative training methods resulted in the excellent preparation of the EVA crew for their tasks.

EVA lessons learned were also used by the EVA designers and trainers for STS-61. Typically, lessons-learned databases are maintained for internal use by the various disciplines of flight planning personnel. Because these databases are kept informal, they often contain conflicting advice resulting from differing opinions expressed by different crewmembers and other personnel. If these databases were edited to represent clear guidelines, where possible, and made available to the greater NASA and customer community, they would be of greater use to payload and mission designers.

A lessons learned steering committee led by the NASA Office of Safety and Mission Assurance has begun working to develop new systems and procedures to enhance the availability of aerospace-related lessons both among the NASA centers and between NASA and other government agencies.

Mission Director's Recommendation No. 49: The Space Shuttle Program should formalize its various lessons-learned databases and make them widely available to the Shuttle customer and design communities. The EVA and Crew Equipment Project Office might be the proper owner of the EVA and RMS lessons databases.

Mission Director's Recommendation No. 50: NASA should complete the development of a NASA-wide and interagency database of lessons learned from aerospace programs. Input of data from government programs should be program requirements. The database should be well publicized and easily accessible to NASA program and project managers.

The sixth implementation recommendation from the group task force is that NASA should upgrade its EVA capability, including the use of state-of-the-art EVA tools and training methods. The improvements in EVA training employed during STS-61, including RMS-II, Nitrox, some of the air-bearing equipment, and virtual reality, were important to the success of the mission. Such improvements and innovations should be continued and expanded upon.

Mission Director's Recommendation No. 51: Expand and use state-of-the-art EVA tools and training methods (such as RMS II presently installed at MSFC's NBS, Nitrox, virtual reality, improved air-bearing techniques, et al.) to perform training and EVA tasks with maximum efficiency. Investigate other potential sources of ideas for improvements, including time-motion studies and the experiences and techniques of the Russian space program. Especially consider improvements in the area of thermal protection of the EVA crewmembers, assessing the desirability of devices such as hand warmers and an EVA infrared temperature sensor.

Mission Director's Recommendation No. 52: Fund and develop a fully integrated EVA training facility (such as the proposed JSC Neutral Buoyancy Laboratory [NBL]), which would incorporate a large capacity pool, state-of-the-art RMS simulator, Nitrox, flight-like video and audio communication capabilities, and any other features useful to provide the flight crew and flight controllers the best possible end-to-end EVA training.

Mission Director's Recommendation No. 53: For Space Station EVAs and for other EVAs with worksites too large to fit into underwater training facilities, develop alternate training method(s) that will accomplish reliable end-to-end timeline quantification and crew training. Consider the use of virtual reality to provide three-dimensional training for handling large masses and to develop methods of translating objects that cannot be simulated in water-training facilities.

On October 14-15, 1992, the eighth HST Payload Operations Working Group (POWG) EVA Working Group (EVAWG) splinter meeting was held. Minutes of the meeting were released December 6, 1992. Preliminary EVA scenarios were presented at this meeting for consideration. The servicing tasks were listed in three priority categories:

<u>Primary</u>
COSTAR
WF/PC II
<u>Secondary</u>
Solar Arrays II
<u>Tertiary</u>
RSU 2
DF-224 Coprocessor
GHRS Repair Kit
RSU 3

The preliminary timelines projected that these tasks could be accomplished in three six-hour EVAs.

There was also a discussion of the possible RMS II and Nitrox upgrades to the NBS at MSFC. The Nitrox system was scheduled for completion in February 1993, and the EMU backpacks for the Nitrox system were scheduled for June 1993. Additional funding was needed for the RMS II. The upgrading of the RMS facility at the NBS had been recommended by the <u>HST SM 92.1 Executive Summary Report</u> (April 17, 1992) and by General Stafford's HST SM Review Team's first report (September 18, 1992), but it was stated by the EVAWG that the EVA community did not consider the RMS II to be required for STS-61. These upgrades are discussed below in connection with the recommendations from the Stafford team's February 11-12, 1993, meeting.

Also during the EVAWG, a presentation was made detailing the recently updated crew-induced load criteria for EVA hardware. The new requirements were greater than had been previously presented to GSFC personnel, which they had been using to design their EVA hardware. These new criteria had not yet been incorporated as overall Shuttle Program requirements. The representative of JSC's Loads and Dynamics Section agreed to work with GSFC personnel to determine if the criteria should be applied to the specific hardware and tasks to used for STS-61.

From October 5 through November 13, 1992, another series of NBS evaluations was conducted. This series of twenty-three tests, including thirteen with the STS-61 EVA crewmembers as subjects, provided the crew with familiarization of all the then-nominal ORU change-outs; evaluated change-out of WF/PC without the use of the RMS and with and without the use of the WF/PC installation tool (WIT); and evaluated new ORU hardware concepts and new space support equipment (SSE) designs.

The first HST mission status telecon was conducted on November 25, 1992. It was chaired by Mr. Hal Lambert, manager of the Space Shuttle Integration and Operations Office. These meetings would later be held biweekly. On February 18, 1993, Mr. Lambert was designated as Mission Manager for STS-61 by the Space

Shuttle Program Manager and was placed in charge of an HST SM-1 Management Team, which included the Flight Integration Manager, the HST Program Manager, the Payload Integration Manager, the Cargo Engineering Office Manager, the Lead Flight Director, the Payload Commander, the chairperson of the HST Tools Configuration Control Board (CCB), JSC's Materials Branch Chief, a representative of the Orbiter Project Office, the Space Shuttle Safety, Reliability and Quality Assurance (SR&QA) Office Manager, GSFC's Associate Director of Flight Projects for HST, the HST Flight Systems and Servicing Project Manager, a representative of KSC's Shuttle Payloads Operations Division, and the KSC Launch Site Support Manager. On March 30, 1993, a representative of the STS-61 Mission Director was added to the team membership. The team was "established to provide management overview and resolution of issues associated with the mission. This team will be responsible for coordinating the integration activities between GSFC, JSC, and KSC, maintaining overall program schedules, insuring mission capabilities and mission priorities are compatible and directing the activities in support of this mission as necessary to ensure mission success." The team was "not intended to replace the existing management structure, but to facilitate problem resolution and increase the mission visibility throughout the existing system. The HST SM-1 Management Team will work with the Mission Director to keep him informed of the status and progress of HST repair preparation."

Topics of discussion in this first HST mission status telecon included the tracking of the action items generated by the Stafford and Fitts HST review teams. One of the action items assigned during this telecon directed the chairman of the HST Tools CCB to ensure that proper certification had been or would be accomplished for all EVA tools. The EVA tool certification for STS-61 was a difficult and controversial problem and is discussed above in connection with the recommendations made in the August 8, 1992, report of Dr. Greenfield's Program Review Team and below in connection with Mission Director's Recommendation No. 75.

A team was chartered by the Space Shuttle Program Office to evaluate the causes for the substantially greater time required to perform the STS-49 Assembly of Station by EVA Methods (ASEM) EVA, than was predicted preflight. This ASEM Process Improvement Team (PIT) released the report of its findings on December 3. 1992. The team recommended the establishment of formal working groups for EVA hardware and define any improvements needed for HST. The HST Tool CCB served as the formal working group for this mission. Significant improvements were made to the EVA hardware for STS-61. The EVA and Crew Equipment Project Office has since been established and should serve as the working group for all future EVA missions.

The ASEM PIT's report mentioned that some on-orbit tasks could not be performed because of suit stiffness, even though they were easily performed during WETF training. Training suits have been empirically demonstrated to be more flexible than flight suits. This concern led to the increase of EMU pressure during many of the HST training runs in an effort to increase stiffness. However, the HST EVA crew reported after the mission that the stiffness of the flight space suits was still greater than that of the training suits at the higher pressure.

Mission Director's Recommendation No. 54: For EVA flight crews, develop and provide training EMUs that have flight-like stiffness.

Underwater facilities are used for the greatest amount of EVA training. Working in water has subtle and potentially misleading qualities when compared to working in space. The Mission Operations Directorate has developed a set of such items to be included in the crew training briefings to help prevent negative training. The ASEM PIT recommended that this list be completed and reinforced to the crew during their water training.

Mission Director's Recommendation No. 55: To minimize negative EVA training, continue to quantify shortcomings of training facilities and to make sure that the differences between the training and flight environments are well understood by the flight crew. Work to eliminate these differences where possible. Also, where possible, provide alternate part-task training to compensate for facility shortcomings. Maximize the repeated exposure of actual flight hardware to the crew throughout their training.

The ASEM PIT recommended that the Flight Crew Operations Directorate and JSC Medical Operations assess the potential benefit of implementing a strength and conditioning program for EVA crewmembers. The services of a professional training coach and a training regimen were provided to the STS-61 EVA crew. While fatigue has not yet been a significant problem in Shuttle EVAs, such a program would serve to enhance a crewmember's capabilities and improve the probability of task completion in the event of other difficulties during an EVA.

Mission Director's Recommendation No. 56: Continue the refinement of the strength and conditioning program in which STS-61 EVA crewmembers participated. Implement this program as a requirement for all assigned EVA crewmembers.

On December 3, 1992, Col. Richard Covey, Comdr. Kenneth Bowersox and Mr. Claude Nicollier were announced to be the final three crewmembers for the STS-61 mission. Mr. Nicollier and Comdr. Bowersox were the primary and backup RMS operators for the mission. Earlier assignment of these two crewmembers would have allowed them to participate extensively in the March, August, and November 1992 NBS development and training runs. This earlier involvement would have more greatly enhanced the critical coordination required between the RMS operator and the EVA crewmembers. See Mission Director's Recommendation No. 15.

The third HST SM-1 Flight Techniques Panel meeting was held on December 11, 1992. Topics discussed during the meeting included the potential use of the WIT. The panel decided to plan the task without the use of the WIT. The subject of rendezvous with HST on flight day 2 was also discussed. The crew expressed a desire to consider a day 2 rendezvous only in the event of a reduced-duration flight.

The second STS-61 Mission Status Telecon was also held on December 11, 1992. During this meeting, the contamination specialist on the Mission Management Team was assigned actions to evaluate the potential for contamination caused by the chafing of painted EVA handrails by EVA tether hooks and whether it was required to replace the entire Orbiter payload bay liner for STS-61.

John Young released memorandum AC5-92-53 on December 16, 1992. In this memorandum, he recommended that, because of the physiological performance degradation induced by sleep shifting, the launch and EVA activities should not occur at night. Although daytime launch and mission operations are desirable goals, it is usually impractical to impose such a requirement on rendezvous missions. It is prudent to maximize the chances of success for night missions. Sleep-shifting regimens currently used by NASA for the flight crews have been effective in minimizing performance degradation. Sleep shifting for mission support personnel is discussed in connection with Mission Director's Recommendation No. 90.

Mr. Young also suggested that NASA consider narrowing the launch window to maximize ascent performance. For STS-61, it was determined that ascent margin was adequate with the longer window, and that the longer window was desirable to accommodate small problems in the launch countdown. For Space Station missions, however, the launch window is expected to be approximately five minutes per day. Small problems during Space Shuttle countdowns are not uncommon, and some launches occurred only because of relatively large windows. The Shuttle launch teams have little experience with requirements to launch on time. On the basis of STS-61 post-flight discussions, the Space Shuttle Program performed a launch probability study focused on the likelihood of successfully launching the Shuttle during this five minute window.

Mission Director's Recommendation No. 57: The Space Shuttle Program should review the current launch criteria and procedures and incorporate changes that would safely enhance the likelihood of supporting the expected requirement for a five-minute launch window for Space Station missions.

The STS-61 Cargo Integration Review (CIR) was held January 6-8, 1993. Its purpose was to ensure compatibility of flight operations planning and engineering hardware and software design with payload requirements. During the review, the planned launch date was determined to be December 2, 1993. GSFC personnel agreed during the meeting to develop EVA scenarios to be followed in the case that only one or two EVAs were available during the mission.

A number of issues and problems were discussed during the CIR. GSFC provided length data for their starboard flight support system (FSS) cable that differed significantly from their wiring mockup that had been used for the design of Orbiter wiring for the mission. Consequently, Orbiter cable routing had to be redesigned and the associated controlling documentation required major changes.

Another issue raised during the CIR was the launch location of the portable foot restraint (PFR) to be used for operations with the HST Tool Box. The PFR socket on the tool box had not been certified to withstand launch and landing loads with the PFR installed. Significant EVA time savings could be realized, however, if the PFR could remain attached to the tool box instead of being transferred to another location at the beginning and end of each EVA. During the January 29, 1993, HST status telecon, $200,000 was approved for the redesign of the PFR and the tool box to withstand launch and landing loads.

Also at the CIR, there were open concerns of possible contamination from the crew compartment, EMUs, tool stowage foam, aft shroud beta cloth, tools, the ICBC, and paint chips caused by the chafing from EMU safety tethers. All of these concerns would eventually be satisfied by test or analysis. Another open contamination item was the fact that KSC had not yet agreed to implement GSFC's contamination control plan for operations at KSC. KSC later did approve and implement the plan.

There was discussion during the CIR related to the Orbiter's center of gravity (CG). At the time of the CIR, STS-61 appeared to meet the return-to-launch-site (RTLS) CG location requirements after incorporation of several relief options, including installation of extra weight in Orbiter bay 13 (aft ballast). Concerns existed, however, that any cargo modifications or additions could adversely affect the CG location.

At the time of the CIR, the RMS clearance assessment for some of the EVA tasks and RMS maneuvering time estimates for incorporation into EVA timelines had not been completed. The potential for these maneuvering times to cause the EVA timelines to increase, as well as not-yet-defined photographic requirements and the possibility that new tasks would be added to the EVAs, caused EVA personnel concern that not all the required tasks could be accomplished in the three EVAs that were scheduled. A CIR discrepancy notice (DN) submitted by the Mission Director's Office recommending that a fourth EVA be added was disapproved because the issue was currently being worked by upper level NASA management. The number of scheduled EVAs is further discussed below in connection with the February 2, 1993, update of the Flight Requirements Document and in connection with the briefing to General Pearson on March 9, 1993.

On January 17, 1993, the first of the "EVAs of opportunity" was conducted during STS-54. Although the "EVAs of opportunity" concept was intended to perform EVAs to evaluate techniques and increase capabilities for future missions such as HST servicing and Space Station construction, the STS-54 EVA included little activity of direct benefit to the HST EVAs. The decision to perform the EVA on STS-54 had been made approximately three months before the flight. Restrictions were imposed on the development of this EVA requiring that it be accomplished with no additional training, no additional hardware, and no significant impact to the flight plan or to payload operations. As mentioned above, recommendations had been made by the Fitts team (July 17, 1992) to perform in-flight dry runs of difficult HST tasks and by the Intelsat group (August 14, 1992) to take advantage of opportunities to demonstrate EVA technologies and capabilities to the maximum practical extent. If these recommendations had been implemented sooner, the STS-54 EVA could have been designed to be of greater benefit to HST SM-1. See Mission Director's Recommendation No. 10.

A tool familiarization meeting was conducted in Houston on January 20, 1993. It was announced in this meeting that tools controlled by JSC would be considered government furnished equipment and that GSFC tools would be considered payload hardware. This different treatment of hardware led to confusion over certification requirements and methods and over requirements for data reporting. See the discussion related to the recommendations contained in Dr. Greenfield's Problem Review Team's August 8, 1992, report and the discussion related to Mission Director's Recommendation No. 75.

On January 26, 1993, Dr. Greenfield's PRT released their second report, which resulted from the team's meetings in conjunction with the CIR earlier in the month. One of the recommendations in this report was that a joint GSFC/JSC/KSC team develop a configuration-controlled master list of the HST and Orbiter tools required to support the mission. The STS-61 HST Tools and Crew Aids Master List was baselined by JSC's Payload GFE CCB on January 28, 1993. Although the list was controlled at JSC, the responsibility of certifying the tools remained at the NASA centers that produced the individual tools. See Mission Director's Recommendation No. 75.

The PRT recommended that NASA investigate options to combine the unscheduled EVA for payload deployment with the Orbiter safety contingency EVA. While the Orbiter contingencies for which EVA astronauts are trained are not expected to take a full six hours to perform, it is important to not assume that such an EVA could be combined with a payload EVA. Because the safety of the crew and the Orbiter is the top priority in mission planning and execution, consumables budgeted for Orbiter contingency EVAs should not be used for any other activities.

Mission Director's Recommendation No. 58: Shuttle consumables reserved for Orbiter contingency EVAs should not be reallocated for any other purposes.

The PRT recommended that NASA perform an independent peer review by experienced EVA astronauts to assess the planned operations and training approach. At the direction of the STS-61 Mission Director, an EVA Peer Review Team (EPRT) was formed in July 1993. It was led by Col. Jerry Ross and was composed of NASA EVA and HST experts and current and former EVA-experienced astronauts. The EPRT assessed the training plan, including options in case of a launch slip. They reviewed nominal and contingency EVA timelines and procedures, and the EVA tools and hardware verification plan. They conducted extensive interviews with the training team, the integrated operations team, and the mission management. EVA-experienced astronauts on the team both directly observed crew training and personally performed key nominal and contingency procedures. STS-61 EVA timeline enhancements resulted from the implementation of the EPRT's recommendations to move the stowage location of the primary EVA tools from the payload bay to the middeck, their suggested improvements to the RSU change-out procedure, and their recommendation to perform parallel EVA operations. The EPRT also assessed the possible use of a three-crewmember EVA and the performance of back-to-back EVAs, switching crew during the same day, and determined that neither of these options would benefit the HST SM-1.

The PRT recommended that the quantity and nature of ground commands during the EVA be reviewed and verified to cause the minimum possible time impact. They also recommended that the increased use of onboard, aft deck payload commanding be considered. The commanding that was executed during STS-61 was well coordinated and performed in a timely manner. This good performance was partly a result of practice that occurred during JISs for the mission.

Mission Director's Recommendation No. 59: For HST servicing missions and for Space Station missions, continue to achieve the proper balance of payload commanding performed from the ground and performed by the flight crew. To the extent practical, maximize the amount of commanding which can be performed by the flight crew, to avoid delays caused by waiting for a good air-to-ground communications link. Thoroughly rehearse and evaluate the commanding protocols during joint integrated simulations.

Dr. Greenfield's team recommended that the aft flight deck commanding of HST be verified preflight in an end-to-end test between the Orbiter and GSFC. Communications and commanding testing done in preparation for STS-61 revealed problems in software and a potential data link problem (inverted data) which might require panel rewiring by the crew during flight. A special cable was flown on STS-61 to be used for this purpose if needed. This rewiring was not required during HST SM-1, because the in-flight acquisition of signal resulted in data of the proper polarity (not inverted).

Mission Director's Recommendation No. 60: Continue to maximize the amount of end-to-end communications and commanding testing performed before critical missions.

Mission Director's Recommendation No. 61: For the next HST servicing mission, fully understand the potential for acquiring inverted data from the HST. If the capability for in-flight rewiring is determined to be necessary, make the necessary preflight modifications to Orbiter equipment to allow the crew to perform this action with minimal effort (e.g., operating a simple switch).

The Flight Requirements Document was revised February 2, 1993, to include a mission duration of nine days plus two payload contingency days and two landing contingency days. The revision also changed the number of EVAs to three scheduled EVAs plus one payload contingency EVA and one Orbiter contingency EVA (3+1+1), even though MOD planning at this time assumed a 4+2+1 EVA capability. The Shuttle Program preferred to delay the commitment to additional EVAs in order to discourage the addition of tasks of lesser importance. The number of scheduled EVAs is further discussed in connection with the presentation to General Pearson on March 9, 1993.

At the request of the NASA Administrator, Dr. Joseph Shea formed a team to review HST SM-1. His Task Force on the HST Servicing Mission held its first meeting, at GSFC, February 4-5, 1993. The task force's findings from this and its subsequent meetings were published in May 1993, and are discussed later in this section.

The second meeting of General Stafford's HST SM Review Team occurred at JSC on February 11-12, 1993. The team released the report of their findings March 15, 1993. The team recommended that NASA strive to conduct JISs with EVA crewmembers located in the NBS at MSFC. One such JIS was conducted on October 8, 1993.

The Stafford review team repeated their September 1992 recommendation to upgrade the RMS simulator at MSFC's NBS, and recommended the incorporation of a Nitrox breathing system. The team believed that insufficient Shuttle Program management attention had been given to these upgrades prior to the February meeting. Neither of these systems was upgraded in time for the June 1993 NBS testing. Several factors contributed to the delay in incorporation of the two systems. Although an informal group began working on the Nitrox system in January 1992, its work was not given high priority by the Centers or by the Space Shuttle Program until late in the STS-61 flow. A formal Nitrox working group had been in the process of formation at the time of the February Stafford team meeting. Needed funding authorization was not provided by JSC to MSFC until early 1993. The RMS upgrade did not receive program recognition as a high priority until February 1993. As a result of these delays, neither upgrade was in place in time for the largest series of HST training runs, which occurred in June 1993. MSFC personnel were later able to overcome significant technical obstacles, and to perform upgrades of both systems before the October 1993 tests. Both systems were of great significance in allowing the crew to validate timelines and to receive valuable end-to-end timeline training.

Mission Director's Recommendation No. 62: Identify requirements for joint center operations as early as possible in the mission flow to allow time to resolve technical, budgetary, and administrative issues without causing impacts to mission schedules.

Mission Director's Recommendation No. 63: The Space Station Program should thoroughly assess requirements for integrated RMS/EVA training in comparison to available facilities. If it is determined that facilities at other centers are required (e.g., MSFC's Neutral Buoyancy Simulator), necessary intercenter agreements should be established as soon as possible to ensure availability and proper configuration of facilities.

The Stafford team recommended the assignment and training of a backup crew. This recommendation had been made by the STS-61 Mission Director to the team during the February meeting. Mr. Greg Harbaugh, the EVA Capsule Communicator (Capcom) for STS-61, was also named as backup crewmember on March 9, 1993. The extra EVA training he received as backup crewmember provided the capability to minimize the schedule impact in case one of the EVA crewmembers became unable to support the mission. It also provided Mr. Harbaugh greater familiarity with the EVA tasks than he would have received otherwise, and therefore enhanced his capabilities as Capcom. He was also better able to contribute to the efforts of the EPRT, of which he was a member.

Mission Director's Recommendation No. 64: For HST servicing missions and for critical Space Station assembly missions, NASA should consider designating a crewmember to serve as both EVA Capcom and backup EVA crewmember.

The Stafford team also recommended maximization of the scope of human thermal vacuum testing (See Mission Director's Recommendations No. 8 and No. 9.) and the development of a mission management plan (See Mission Director's Recommendation No. 36.)

A biweekly STS-61 mission status telecon was also held on February 12, 1993. During the meeting, schedules were presented showing that the RMS II installation would not occur in time for the June 1993 NBS training runs. It was also announced at the meeting that the EVA DTO had been approved for STS-57, and that each task in the EVA would have HST or Space Station relevance.

An EVAWG meeting was held February 23, 1993. This meeting included discussions of concerns about the WF/PC cavity cover, which was later deleted; foot restraint load requirements that had recently been increased, and the recently baselined task to replace four power distribution unit (PDU) fuses which had been incorrectly sized in their original design.

During the POWG meeting that was held February 24-26, 1993, a discussion took place involving expected thermal environments during STS-61. HST Project Management had designed thermal coatings for EVA tools and crew aids based on the assumption that the Orbiter would perform three attitude maneuvers each orbit. However, at the time of the POWG meeting, the Shuttle Program was planning to fly an inertial attitude (with no maneuvers) which would result in a colder thermal environment than was used for the GSFC tool coating design. Since both of the above attitude scenarios complied with GSFC's published ORU environment constraints, GSFC personnel were cautioned to make design decisions based on the thermally worst-case attitude allowed by the ORU constraints. In this case, improved communication between the two NASA centers could have prevented wasted effort, and possibly inadequate hardware design.

Mission Director's Recommendation No. 65: Maximize communication among all organizations supporting critical missions, both before and during the missions, to minimize wasted effort and inaccurate data. This communication can be facilitated by periodic technical interchange meetings and by regular management meetings similar to the biweekly STS-61 mission status telecons conducted by the Mission Manager. Also maximize use of electronic systems for the transfer of verbal and graphical communications, including photographs and engineering drawings, among the entire mission team.

On February 25, 1993, the Shea task force held a meeting the Lockheed Missiles and Space Company (LMSC) headquarters. The task force's findings from this and its other meetings were published in May 1993, and are discussed later in this section.

A JSC/MSFC Nitrox Combined Working Group meeting was held at MSFC February 25, 1993. Discussion items at this meeting included the maintenance of air capability as a backup to Nitrox for the June runs, and that because of different dive table requirements recognized at the different NASA centers, JSC support divers and suit subjects would have different time limits imposed upon their dives than would personnel from other centers.

Mission Director's Recommendation No. 66: Establish a single NASA-wide set of underwater diving requirements (dive tables).

In early March 1993, STS-61 crewmembers traveled to the facilities of the vendors who were supplying the HST replacement hardware for training sessions using the actual flight ORUs. This training proved to be extremely valuable, as it enabled the crew to become familiar with mechanisms that may have functioned differently from the training hardware. Differences were made known to the crew to minimize negative training that may have otherwise occurred. While it is always desirable to train with exact duplicates of flight hardware items, it is often impractical to produce training hardware to the exact flight specifications. In these cases, it is important that the crew be given the chance to see, handle and operate the actual flight hardware even if only in a restrictive controlled setting (clean room).

Mission Director's Recommendation No. 67: For critical EVA missions, continue to maximize the amount of preflight experience the EVA crew receives with the actual flight hardware.

On March 4, 1993, the Mission Coordination Team was established. It was established to coordinate Level I activities and to oversee Level II and III management activities during mission preparation. The team was chaired by the STS-61 Mission Director, and included management representatives of the Space Shuttle Program and the HST Program Offices.

On March 8-9, 1993, at NASA Headquarters, the Shea task force held the last of its four meetings. The report of their findings and recommendations was released in May 1993, and is discussed later in this section.

On March 9, 1993, mission management personnel made informal status presentations to NASA Associate Administrator for Space Flight, General Jed Pearson. During this meeting General Pearson indicated that he did not want the mission to be in progress over the Christmas holidays, because it would then interfere with scheduled maintenance activities at KSC, causing schedule and cost impacts to KSC operations. If the launch were to be delayed by more than two weeks, then it would be rescheduled for January 1994. He also indicated that he would not require the launch or landing to occur in daylight. It was reported to General Pearson that Dr. Shea's task force was concerned that the mission was too constrained by the Shuttle Program's reluctance to increase the number of scheduled EVAs beyond three, and that EVA and contingency planning and training were being negatively affected. The task force was expected to recommend the scheduling of five EVAs to ensure maximum timeline margin. Two weeks after this meeting, the mission plans were officially changed to include five scheduled EVAs.

During the biweekly HST mission status telecon on March 12, 1993, GSFC personnel were authorized to proceed with the Nitrox facility construction in the

NBS. This upgrade is discussed above in connection with the recommendations from General Stafford's task force's February 11-12, 1993, meeting.

On March 17, 1993, the STS-61 FPSR was conducted. During this review, approval was given to several change requests (CRs) which added items and evaluations to the mission, including the Orbiter drag chute DTO, two payload bay color television cameras, a number of medical DSOs, and an EVA dosimetry evaluation DSO. Approval was also given to the submittal to the Program Requirements Control Board of a CR adding a secondary payload, the Air Force Maui optical site calibration test (AMOS), to the mission. The subject of DTOs and DSOs is discussed below in connection with Mission Director's Recommendation No. 88.

It was announced during the FPSR that stowage volume in the crew compartment was full, and that any additions of stowed items would require deletions of other items from the manifest. However, after the later approval of some innovative stowage methods, room was found for the addition of items in the crew compartment, including some of the EVA tools and the PILOT DTO hardware.

A discussion during the FPSR addressed the possibility of changing the nominal mission length from nine to eleven days. No one in the meeting was aware of any significant problems that would be caused by this increase. The idea of manifesting six EVAs was also discussed. It was thought that the training and simulation schedules would not be able to accommodate more than five EVAs without requiring a launch delay.

On March 22, 1993, the second revision was made to the STS-61 Flight Requirements Document. It was updated to reflect a mission duration of eleven days plus two landing-contingency days (11+2). The number of EVAs was also updated to five scheduled EVAs plus two payload-contingency EVAs and one Orbiter-contingency EVA.

At the biweekly HST mission status telecon held March 26, 1993, it was reported that the HST had entered a "safe" mode, believed to be caused by a malfunctioning SA drive electronics (SADE) unit. At this time, it was not yet considered very likely that a SADE replacement would be added to the mission. The addition of the fuse plug task was discussed. Both of these tasks would later be added to the mission.

On March 30, 1993, a technical interchange meeting was held in which it was established that hitch pins would need to be reinstalled by the EVA crewmembers only into PIP pins that were oriented in the Z axis and into ones that were known or suspected to be damaged. The installation of hitch pins is difficult and time-consuming while wearing EMU gloves. This decision significantly reduced the number of required installations.

On April 6, 1993, Dr. Greenfield's PRT released the report resulting from its third meeting, which had been held in conjunction with GSFC's Test Readiness Review (TRR) on March 23-25, 1993. One of the recommendations from this report was that NASA should immediately begin planning a contingency HST servicing mission to occur as soon as possible after STS-61 to accomplish the tasks that were not performed during STS-61. In response to this idea, the Space Shuttle Program led a study into the possibility of such a mission. It was determined that the timing of the contingency mission was extremely dependent upon which tasks would have to be rescheduled. It was decided that if one of the primary HST servicing tasks were not accomplished during STS-61, then the HST Program Office would request a second mission as soon as possible. Until the required tasks were known, it would not be practical to actually manifest such a mission. However, normal mission planning should include assumptions that not all scheduled tasks will be accomplished.

Mission Director's Recommendation No. 68: For the second and subsequent HST servicing missions, mission planners should again develop a list of primary tasks, which would trigger a contingency mission if not completed.

The PRT also recommended that a senior NASA official from the science organization, which was the customer for this mission, be designated as the Official-In-Charge (OIC) of the execution of the HST SM-1. It was decided that the mission management structure that had been established by the Space Shuttle Program Project Plan for STS-61 was adequate for mission support. An OIC was therefore not designated.

The PRT recommended that all individuals involved in the mission, both technical and management personnel, should participate in the JISs to the extent possible. See Mission Director's Recommendation No. 21.

The PRT observed that it is important that real-time responsibilities and clear lead and support roles for EVA procedures replanning and timeline estimation be recognized and enforced. The EVA replanning efforts of the mission support team were not well coordinated during the initial JISs, but were significantly improved by the time of the mission as a result of the JISs.

The team suggested that, given the apparent discrepancies between the priorities of the tasks in the nominal mission EVA timelines and the priorities of the reduced duration mission, NASA should verify that the nominal timeline was designed as if every EVA day were the last EVA day of the mission.

Mission Director's Recommendation No. 69: To the extent possible, critical EVA mission timelines should be arranged so that at the completion of each EVA day, the payload (or Space Station) is in the

best possible configuration to be left in, in case the Orbiter must deorbit before the next EVA.

The team also wanted NASA to verify that there were redundant methods of accomplishing critical tasks in case the primary tool or device were lost or broken. See Mission Director's Recommendations No. 12, No. 19, and No. 43.

The PRT also recommended timely failure analysis of the ORUs returned from orbit to determine whether the improvements to the new designs had fixed the right problems.

Mission Director's Recommendation No. 70: Perform sufficient failure analysis of returned HST components to ensure that failure causes are understood. Also look for signs of degradation other than those which caused the failures.

During the biweekly HST mission status telecon on April 9, 1993, it was announced that STS-61 would not include the replacement of the fine guidance sensor (FGS) which had degraded in February 1993. Procedural compensation had been developed for the degradation. It was also announced that STS-61 would not incorporate the capability to send video images from the ground to the Orbiter.

The HST science writers' workshop was conducted at GSFC on April 20-21, 1993.

During the May 7, 1993, HST mission status telecon, it was announced that during testing of the deployable optical bench of COSTAR, some physical interference was encountered and some debris was generated.

An Orbit Flight Techniques Panel meeting was held May 14, 1993. The topics of discussion included procedures needed to prevent HST contamination caused by Orbiter water dumps.

A POWG meeting was held May 24-26, 1993. This meeting served as a dry run for the FOR to enhance the maturity of the mission documents to be submitted for the real FOR. During the meeting, GSFC and JSC personnel agreed to develop EVA scenarios for use if only one, two, three, or four EVAs would be available due to Orbiter or mission constraints. JSC personnel agreed to draft a real-time operations contingency management plan to document guidelines for "tiger team" activity for significant off-nominal situations outside documented contingency plans. GSFC personnel agreed to consider the scheduling of SA blanket retraction during the night before the SA change-out EVA, instead of the morning of the EVA, to allow more reaction time in case problems were encountered. At the conclusion of the meeting, the chairman of the POWG related his reasons for his confidence that the STS-61 would be successful. His reasons included that the GSFC team was largely the same one that had supported the HST deployment during STS-31, that the GSFC internal simulations had been occurring and exercising their interfaces with JSC, and that a large number of JISs were to be conducted. The Space Shuttle Program Deputy for Program Integration expressed his desire that all relevant HST technical data be available at JSC during the mission.

Mission Director's Recommendation No. 71: The Mission Operations Directorate should develop a computerized system to support decision making during real-time EVA mission replanning. The system should provide the flight team with access to information related to the EVA timeline and procedures; tool histories, performance capabilities, and locations; and payload configuration. It should also provide access to photographs and engineering drawings. See Mission Director's Recommendations No. 25 and No. 41.

Dr. Joseph Shea's Report of the Task Force on the Hubble Space Telescope Servicing Mission was released in May 1993. The team recommended that top management continue paying close attention to the HST SM-1 mission management organization. The use of formal reviews was also endorsed. See Mission Director's Recommendation No. 37.

The Shea team recommended that training include end-to-end JISs of the EVAs. JISs typically incorporate significant malfunctions to test and enhance the flight control team's ability to make changes to the originally planned timelines. The recommendation that the EVAs be practiced fully during JISs is, therefore, not totally practical. However, it is valuable to provide to the flight control team and the flight crew with as much experience with the nominal timeline as possible.

Mission Director's Recommendation No. 72: To the extent practical, expose the participants of joint integrated simulations to all the nominal mission activities.

Dr. Shea's team recommended that the HST Project conduct a quantitative assessment to determine the risk of verifying the status of all subsystems (both A and B sides) before SM-1. The HST Project did reassess their rationale and again decided that not all redundant systems should be verified. This decision was approved by NASA administration and mission management. Part of the rationale for not performing testing of redundant paths was the fear of entering into an irrecoverable configuration in the event that the redundant path were not functional. Given the improved health of the HST resulting from the HST SM-1, it may now be less risky to verify the redundant systems.

Mission Director's Recommendation No. 73: Reassess the rationale for not verifying the redundancy of all HST systems, now that the

telescope has been serviced. Consider verifying the function of redundant elements whose health is not now known, where such verification would not risk the health of the HST. This verification should be performed early enough to allow replanning of the second servicing mission, should components be in need of replacement.

The Shea team also recommended that an integrated assessment of contamination control procedures and plans for the HST servicing missions be conducted. Such a preflight assessment was performed under the direction of Dr. Michael Greenfield. His PRT reviewed the Contamination Control Master Plan (CCMP) developed by the HST Project, which addressed contamination budgets for each HST SM-1 instrument, handling at KSC, and on-orbit possibilities for contamination. The PRT compared the current requirements documentation to that used for the initial build of HST. The HST SM-1 version of the CCMP was compared to that used for the HST deployment mission. The PRT found only minor differences, which they considered to be inconsequential. The PRT reviewed the resolution of the problems encountered in the testing of the COSTAR. They assessed the design changes implemented into WF/PC II to prevent the self-contamination experienced by WF/PC I. The PRT reviewed testing and hardware changes implemented to minimize on-orbit contamination. They reviewed flight procedures for possible threats. In all the above assessments, the PRT found the contamination requirements and compliance to them to be adequate. The PRT also assessed KSC ground processing guidelines and procedures. The PRT considered them adequate, partially based on the pending successful completion of a special contamination review by KSC following the refurbishment of Launch Pad A and before payload arrival at the Payload Change-out Room (PCR). The PRT released their satisfactory report on October 25, 1993. On October 30, 1993, sand and debris were blown into the PCR at Pad A. The PRT then assessed the investigation and corrective actions undertaken in response to the PCR contamination and found them to be satisfactory. The PCR contamination is discussed below in the listing for October 30, 1993.

Dr. Shea's team also made recommendations related to accelerating the development of EVA timelines and contingency timelines (See Mission Director's Recommendations Nos. 15 and 86), to upgrading the NBS at MSFC (See the discussion of the Stafford team meeting, February 11-12, 1993), to designating and training a backup EVA crewmember (See Mission Director's Recommendation No. 64), to practicing HST tasks on earlier missions (See Mission Director's Recommendation No. 10), and to planning for a contingency mission (See Mission Director's Recommendation No. 68).

The first two STS-61 human thermal vacuum test (HTVT) runs were conducted May 25 and 28, 1993. The more significant hardware problems that were encountered during these tests are discussed below in connection with the July 13, 1993, report from the Brasher team. During the May 28 test, because of multiple previous hardware malfunctions, the crewmember, Dr. Story Musgrave, spent a large amount of time handling the extremely cold tools to test every possible tool interface. From this activity, Dr. Musgrave contracted frostbite injuries on eight of his fingers. These injuries prevented Dr. Musgrave from fully participating in training events for the next few weeks. This injury incident was the subject of a mishap investigation. The final report of the mishap investigation board was released as JSC memorandum NS2-93-147, dated July 8, 1993.

The Payload Safety Review Panel Phase III Review took place June 1-4, 1993. Two payload hazard reports remained open at the conclusion of the review, one involving inadvertent mechanism operations and one covering mating and demating of powered electrical connectors.

During the June 4, 1993, HST mission status telecon, it was announced that the degraded FGS 2 had been successfully used during the previous week. Also announced was the formation of a team led by Mr. Warren Brasher to investigate the hardware problems discovered during the May HTVT runs. The plan for the June NBS runs now called for the backup crewmember, Mr. Greg Harbaugh, to replace Dr. Musgrave for the first runs to allow Dr. Musgrave more time to recover from the frostbite he suffered during his HTVT run.

On June 9, 1993, HST SM-1 status presentations were made to Mr. Brewster Shaw, who had recently been transferred to JSC, serving as the Director of Space Shuttle Operations, in the Space Shuttle Program Office (SSPO). Issues mentioned in the presentations included the tool problems discovered in the recent HTVT and the ongoing Brasher team investigation; the ambitious schedules for hardware delivery to support crew equipment interface tests at GSFC and KSC and for the completion of tool fit checks; the potential addition of the SADE change-out to the mission; and that it was believed by JSC's MOD that GSFC mission support response to real-time contingencies was slow, due to immature contingency documentation, nonexistent preauthorized contingency actions, and somewhat diffused management authority.

During the HST Tool CCB meeting on June 11, 1993, the plan for closure of tool certification discrepancy reports (DRs) and the hardware interface fit-check matrix was presented. This plan was formulated based on comments and recommendations from the Brasher investigation team, whose final report had not yet been formally released.

An unprecedented series of thirty-two three-hour training runs, with the four STS-61 crewmembers and the backup EVA crewmember as subjects, was held June 14-July 2, 1993, in MSFC's NBS. These runs performed timeline verification for all the EVA tasks as well as for some contingency scenarios. They also further cross-trained the astronaut pairs to perform tasks scheduled to be done by the other EVA pair. One of the results of these runs was the indication that there would likely be enough timeline margin to include the replacement of the SADE. During this series, a communications protocol verification was conducted to help ensure the capability to support a full JIS using the NBS in October 1993.

In spite of these accomplishments, however, some of the originally planned major objectives of these tests could not be met. Because the Nitrox breathing system was not yet installed, full six-hour tests, which could be used to better verify timelines for entire EVA days, were not accomplished. Because the new upgraded RMS simulator was not yet installed, valuable coordination training and RMS timeline verification could not be accomplished. The communications protocol mentioned above had originally been planned as a "mini-JIS," but with the runs lasting only three hours, it was not practical to do more than just verify communications.

The KSC Ground Operations Review (GOR) was conducted on June 18, 1993. Issues presented during the review included concerns over the ability of KSC facilities and equipment to support the stringent gaseous nitrogen purge cleanliness requirements. Difficulty in meeting these cleanliness requirements later led to a relaxation of the requirements with the agreement of the HST Project. See Mission Director's Recommendation No. 78 and its associated discussion.

Another GOR item of concern was the potential for conflicting needs for KSC's Payload Hazardous Support Facility (PHSF) control rooms in case of a launch delay of the STS-51 mission by more than one week past its then-scheduled date of July 17, 1993. A favored solution to the conflict, if it were to arise, was the reservation of a trailer to house some of the STS-61 ground support equipment. It was later decided to use such a trailer, thereby eliminating concern over any delay of STS-51. The launch of STS-51 occurred in August 1993.

On July 8, 1993, the STS-57 flight crew EVA debriefing was held. The most significant result of the STS-57 EVA was that the Orbiter-bottom-to-sun attitude that had been planned for several of the STS-61 HST servicing tasks was unacceptably cold to the STS-57 EVA crewmembers. During the debriefing, the STS-61 Lead Flight Director indicated that the STS-61 EVA thermal environment issue was now the top priority issue to be resolved before the flight. JSC's Crew and Thermal Systems Division (CTSD) personnel stated that they were proceeding with the development of EVA gloves that had better thermal protection characteristics than the present glove had.

In a subsequent STS-61 EVA thermal environment meeting on July 8, 1993, the intention to pursue the development of EVA hand-warmers was announced. It was also announced that CTSD personnel would perform higher fidelity thermal analyses of the known EVA thermal environment of STS-57 and the predicted environment of STS-61.

Mission Director's Recommendation No. 74: Prior to critical missions, especially the HST servicing missions and Space Station Assembly missions, perform detailed thermal analysis and modeling to verify that crewmembers and hardware are not subjected to

temperatures beyond their functional limits. Beta angle of the mission's orbital plane(s) should be included in the analysis. This analysis for the Space Station's worst-case altitude, inclination, attitude, configuration, and beta angle should be performed as soon as possible. See also Mission Director's Recommendation No. 10.

On July 13, 1993, the results of the investigation of Mr. Warren Brasher's Tool Review Team were presented to the Space Shuttle Program management. One of the recommendations of the Brasher team was that NASA consider the development of EVA gloves that would have improved thermal protection of the EVA crewmember's hands. CTSD personnel were later able to complete the development of an improved thermal and micrometeoroid garment (cover layer) for the EMU gloves, which had not only greater thermal insulation, but also greater flexibility than the older design. This development was a significant contribution to the success of the STS-61 mission.

The Brasher team also recommended that NASA evaluate the development of a portable EVA hand-warmer. On the basis of results from detailed thermal modeling and analysis, and from further human thermal vacuum testing, it was decided that a hand warmer was not needed for STS-61. See Mission Director's Recommendation No. 51.

Another recommendation of the Brasher team was that NASA perform an analysis of the ability to interface thermally worst-case tools and fasteners (one side hot, other side cold). Thermal analysis personnel at both JSC and GSFC produced the thermal analyses that indicated that tools and crew aids planned for use on STS-61 would be adequate, given the successful performance of the planned fit checks of the interfaces. As an added measure, it was decided that sets of flight contingency socket extensions, both 5/16" and 7/16," would be precisely machined to the maximum allowable tolerances, to ensure that all fasteners could be accommodated by sockets on board the Orbiter. This effort helped ensure the success of the STS-61 EVAs.

The Brasher team recommended that the chairman of the HST Tool CCB, Mr. Steve Poulos, work with GSFC to develop the mechanism by which the CCB would approve changes that affected form, fit or function changes to GSFC's tools and crew aids. Within the limits of the responsibility given to him, Mr. Poulos provided very effective leadership in the coordination of the JSC and GSFC design efforts.

Another Brasher team recommendation was that Mr. Poulos define an increased scope of responsibilities for his HST Tool CCB. These responsibilities were to include assessment and approval of all configuration changes that affected fit, form, or function of all HST crew aids and tools and assessment of GSFC and JSC certification and verification matrices for technical adequacy. While the recommended increased scope was an improvement to the coordination of the tool and crew aid development effort, it was not extensive enough. Since the basic responsibility of hardware certification continued to reside with the NASA center at which the hardware was developed, there continued to exist differences in design and certification philosophy between JSC and GSFC. This situation resulted in discrepancies in the data provided to mission control personnel, which were resolved only very late before launch and with significant effort and management attention.

Mission Director's Recommendation No. 75: EVA hardware, including all tools, supplied by multiple NASA organizations should be manufactured to standardized NASA-wide certification requirements, and be controlled by a single configuration control board. Performance verification (including fit checks and verification of thermal tolerance) requirements should likewise be standardized.

Mission Director's Recommendation No. 76: Technical information, including certification data, related to flight tools and other EVA hardware, should be maintained in a rapidly accessible format to support replanning and failure assessments during missions.

The Brasher team learned that some of the standard EVA tools planned for STS-61 had not been redesigned to meet requirements imposed following the Challenger accident. The team recommended that the certification of the entire Space Shuttle tool inventory be reverified, to ensure that no other tools had been omitted from the post-STS-51L rebaselining effort. The certification of the entire complement of EVA tools and crew aids contained in the STS-61 master manifest list was subsequently reviewed and verified to be satisfactory.

Mission Director's Recommendation No. 77: Verify that the hardware and software to be used for critical mission operations are not to be used outside the operational ranges for which they were certified. Also verify that the certification requirements used for this hardware and software are consistent with current program certification guidelines.

The Brasher team tasked HST Tool CCB personnel with providing a list of hardware failures that occurred during HTVTs. The list follows.

Problem - Insertion forces of the push in, pull out (PIP) pin into the McTether attachment was excessively high or would not go into tool at all.
Corrective action - Apply dry film lubricant to spool to decrease coefficient of friction with housing. Install lighter spring in mechanism. Ensure a minimum radius on pip pin edges, including plunger. Verify ball and socket dimensions to ensure ball does not interfere with spool movement. Reduce acceptable level for pip pin insertion force from ten pounds to no greater than six pounds.

<u>Problem</u> - Force to install and remove tools from tool post was excessively high.
<u>Corrective action</u> - Replace existing ball detent with one requiring lighter spring force. Change acceptance levels for insertion and removal forces from ten pounds to no greater than two pounds.

<u>Problem</u> - Toolbox door panel contingency door removal could not be performed.
<u>Corrective action</u> - Remove material from door side hinge bracket and door panel to eliminate interference. Stress analysis was performed to verify that hinge is still within acceptable margin of safety.

<u>Problem</u> - Tool board No. 5 was difficult to remove from toolbox.
<u>Corrective action</u> - Delrin inserts were added along the bottom of the mounting slots to reduce the friction coefficient between tool board and its mount. All tool board mounts were modified.

<u>Problem</u> - Stud caddie bayonet fitting would not interface with mini-workstation (MWS).
<u>Corrective action</u> - Rework edge radius of bayonet fittings and brackets on MWS to improve fit. Correct differences in allowable tolerances on drawings.

<u>Problem</u> - EVA portable light handle would not clamp securely to handrail.
<u>Corrective action</u> - Change shaft material to reduce susceptibility to galling. Dry film lubricate the interface between the two rams in the housing to reduce sliding friction. Engrave a direction indicator on the EVA knob to indicate tighten and/or loosen. Procedures change to loosen knob prior to handle release.

<u>Problem</u> - Unable to install PIP pin into McTether attachment on three tools. One tool was not restrained on tool post.
<u>Corrective action</u> - Mandatory inspection of McTether to verify that Loctite has not contaminated system. Modify Loctite application and curing instructions. Additional inspection steps performed to verify correct spool displacement. Perform additional thermal acceptance testing to verify proper operation of McTethers.

During the presentation meeting, a discussion was held concerning the temperature of tools in the HST tool box. Mr. John Young suggested that the EVA tools be launched in the Orbiter cabin instead of in the HST tool box. Although the STS-61 crew and EVA training personnel had previously expressed their desire to launch the EVA tools in the Orbiter cabin, the apparent lack of available locker space prevented the adoption of this idea. However, after this idea was again recommended by the independent EVA Peer Review Team and endorsed by the

Mission Director, some innovative stowage methods were implemented which allowed the tools to be located in the cabin.

On July 15, 1993, the HST Program Manager initiated a reassessment of the adequacy of the HST aperture door to prevent contamination of HST optics during the servicing mission. This reassessment considered Orbiter jet exhaust particle impingement to be of negligible concern. However, given that pressure spikes were indicated by the GHRS during STS-61 Orbiter jet firings, such spikes should be assessed for possible contamination implications for future servicing missions. See Mission Director's Recommendation No. 28.

During the HST Mission Status Telecon on July 23, 1993, some of the results from STS-57 were discussed. One result was that all Shuttle missions were now to be required to reserve an additional 330 pounds of aft propellant due to the high usage experienced during STS-57 and some previous missions. Before the imposition of this requirement, STS-61 was carrying a margin of only 30 pounds, so this extra restriction was a significant impact. The second result that was discussed involved the EVA thermal environments expected on STS-61. It was estimated that the coldest of the STS-61 environments, assuming the worst-case beta angle, would be roughly equivalent to the Orbiter-bottom-to-sun attitude that was found to be unsatisfactory during STS-57.

At a July 27, 1993, meeting, GSFC personnel announced their planned action in response to a leak that was experienced in one of the load isolators on their cargo carriers. Their plan was to remove the damping fluid from all the isolators to eliminate the risk of future leaks. They also intended to perform the hazard analysis on the system using a "safe-life" approach instead of the previously planned "fail-safe" method.

The fourth report from Dr. Greenfield's PRT was released July 28, 1993. Because of the large number of tool and hardware interface verifications to be accomplished and the limited amount of time in which to do them, the team recommended that a single office of prime responsibility be defined to establish criteria and priorities for the fit checks. They also recommended the development of a pre-defined priority scheme to ensure that the most important fit checks were the most likely to be accomplished. Although the HST Tool CCB was tasked with approving the close-out of the fit-check matrices of both JSC and GSFC tools, they did not determine the priorities of all the fit checks before they were performed. Neither of these recommendations was totally complied with. See Mission Director's Recommendation No. 75.

The PRT also recommended that the pedigree of the various thermal go/no-go determination methods be investigated to ensure that assumptions are consistent among the various organizations/NASA centers involved in performing thermal verification exercises. The go/no-go gauges used to screen probes, sockets, and bolts were made by different sources and controlled by different NASA centers. The effort to understand what each gauge was designed to check (thermal expansion, machining tolerances, or both) required a significant amount of coordination between centers just before flight. There remained sufficient uncertainty, even after the coordination efforts, that it was decided to make specially sized sockets to accommodate the worst expected temperature differences. See Mission Director's Recommendations No. 8 and No. 75.

The PRT's report recommended that, given the possibility that the HST SM-1 flight hardware KSC nitrogen purge moisture and particulate requirements might prove hard to meet, specific time periods of slightly higher moisture content and particulate counts be allowed. A compromise was later agreed to by KSC and the JPL, setting slightly higher steady-state allowances. However, even the more relaxed moisture requirement was difficult to meet. It is believed that the more stringent purge requirements could have been met with the use of JPL's purge purification equipment.

Mission Director's Recommendation No. 78: For HST servicing missions and all other missions having payloads sensitive to contamination, specify any purge purity requirements early enough in the mission processing flow to allow for verification of the capability to comply with those requirements. Consider the use of special ground servicing equipment (e.g., JPL's purge purification equipment) to meet requirements too stringent to be met with standard equipment.

The PRT recommended that KSC personnel renotify organizations operating in the areas surrounding the payload processing areas of KSC to restrict, during periods of susceptibility, activities that might cause contamination of HST SM-1 hardware. Subsequent to the PRT report, two significant risks to the cleanliness of the payload developed. A lightning-caused grass fire generated significant amounts of smoke close enough to the payload processing facilities to be of concern. The second cause for concern was the blowing of sand and debris into the PCR at Launch Pad A by high winds.

Mission Director's Recommendation No. 79: For HST servicing missions and all other missions having payloads sensitive to contamination, have in place at the launch site a comprehensive plan to protect the payloads from all sources of contamination, including human-generated and natural sources.

Mission Director's Recommendation No. 80: For critical or sensitive missions, minimize the number of any untried or unusual mission preparation activities (e.g., launch pad refurbishment) or flight activities that do not serve to increase chances of mission success.

The PRT also recommended a special contamination review of the recently refurbished Launch Pad A before arrival of the HST payload. Although such a review was performed, neither this review nor the contamination control plan in place at KSC was adequate to prevent the intrusion of wind-blown sand and debris generated during pad modifications into the Pad A PCR and into the Orbiter payload bay. This contamination is discussed below in the entry for October 30, 1993.

Mission Director's Recommendation No. 81: Conduct an independent assessment of the contamination control procedures performed at KSC for STS-61. Assess them for adequacy for the second HST servicing mission. Verify implementation of corrective action to prevent recurrence of wind-blown contamination of the Payload Change-out Room, or any other payload processing facility.

Another recommendation presented by Dr. Greenfield, separate from the report, was that the potential for contamination of HST by a leaking Orbiter RCS thruster be assessed. This issue was addressed by Dr. Lubert Leger at the August 6, 1993, mission status review. He believed that no propellant would condense onto HST surfaces at the temperatures predicted for the mission, and that there was no reason for concern. See Mission Director's Recommendation No. 30.

On July 28, 1993, at the request of the Mission Director, personnel from the Medical Operations Branch at JSC presented the results of their assessment of medical risks of the HST SM-1 EVAs. They had assessed the risks to EVA crewmembers of space motion sickness, decompression sickness, metabolic and nutrition deficiencies, dehydration, fatigue, congestion/barotrauma, cardiac dysrhythmia, radiation exposure, and injury/trauma. The risks they believed to be of the greatest concern were the risk of receiving insufficient nutrition on EVA days and risk of fatigue. To prevent nutritional deficiencies, they recommended that the crew's meal times should be protected and that pre-EVA and optional post-EVA snacks should be provided in addition to the standard in-suit food bar. To help prevent excessive fatigue, the doctors recommended a preflight physical conditioning program and protection of the Appendix K scheduling constraints related to sleep, meals, and exercise. They also considered it desirable to avoid the performance of consecutive-day EVAs by a single crewmember. They also recognized the risk of ear blockage during airlock repressurization, but did not feel that any preventive measures needed to be taken. See Mission Director's Recommendations No. 40, No. 42, and No. 56.

Mission Director's Recommendation No. 82: Continue the practice of not scheduling EVA crewmembers to perform EVAs on consecutive days. Exceptions should be allowed only on a contingency basis, with the concurrence of the crew, the flight surgeon, and the mission management team.

On July 29, 1993, it was reported that during cargo integration test equipment (CITE) testing, errors in the "decom" definitions of all 75 HST discrete measurements were discovered. GSFC and JSC used different conventions for numbering bits in their digital data processing using the Shuttle General Purpose Computer (GPC). The development of the mass memory for the GPC to be used for processing HST measurements had to be interrupted for approximately one month while this discrepancy was corrected. This type of payload digital data definition discrepancy has occurred repeatedly with various previous payloads. A single NASA-wide method for defining digital data parameters would prevent this problem.

Mission Director's Recommendation No. 83: Establish a single NASA-wide set of standards for the definition of payload command and data parameters.

On July 29, 1993, a meeting was held to discuss whether any action should be taken in anticipation of the possible encounter of the STS-51 mission with the annual Perseid meteoroid shower. The concentration of meteoroids was suspected to be greater than that seen on earth in hundreds, if not thousands of years. It was announced that the HST control center was planning to reorient the HST to present the least vulnerable side of the telescope to the meteoroids. After this meeting, it was decided to delay the launch of STS-51 to avoid the Perseids.

On August 3, 1993, Mr. John Young released his memorandum AC5-93-22, addressed to the STS-61 Mission Director. This letter contained a number of concerns and recommendations. Mr. Young suggested that the flying of a drill tool be considered for use in boring out any jammed bolts encountered during the EVAs. The Space Shuttle Program later manifested a type of drill bit called a ball-end mill, which might be used to try to drill out a jammed bolt. At the suggestion of the STS-61 Mission Director's Office, personnel from JSC's CTSD quickly designed, developed, certified, and flew a rotary impact tool, which was hoped to be able to loosen a jammed bolt without causing the debris that would be generated by a drill bit.

Mission Director's Recommendation No. 84: Continue to develop EVA methods to remove jammed mechanisms and bolts. Design goals should include the capability to impart large forces to the jammed mechanisms or bolts, while transferring little force to payloads or other structures.

Mr. Young also suggested that HTVTs be conducted which accurately simulate the worst expected EVA thermal environment to verify the EMU's capability to provide adequate thermal comfort to the STS-61 EVA crewmembers. Such tests were conducted to evaluate thermal modifications to the EMU and WF/PC handholds and operating strategies for the EMU's temperature control valve. An inadequate strategy for the control of EMU temperature was believed to have contributed to the uncomfortably cold conditions experienced by the STS-57 EVA crewmembers. These tests showed that the modified hardware and procedures were adequate to keep the EVA crewmembers thermally comfortable during the expected STS-61 EVAs. See Mission Director's Recommendations No. 8, No. 9, and No. 85.

Another recommendation in Mr. Young's memorandum was that a modification be developed for the EMU that would completely terminate the flow of chilled water through the liquid cooling and ventilation garment (LCVG) at the crewmember's option. This modification was designed and tested in human thermal vacuum chamber testing. It was determined to be unnecessary for STS-61 after incorporation of other modifications to the EMUs and to the EMU cooling-maintenance strategy. However, it is believed that, if the cooling maintenance strategy were not followed properly, resulting in a crewmember's becoming uncomfortably cold, that the LCVG bypass modification could allow the crewmember to regain comfort in significantly less time than in the present EMU design.

Mission Director's Recommendation No. 85: Complete the design of and incorporate the liquid cooling and ventilation garment (LCVG) bypass into EMUs to be used during potentially cold EVAs during critical missions.

Mr. Young also recommended that contingency procedures for all problems that are indicated or implied by engineering data from the HST (such as the non-retractable SA) be trained for and accommodated in the planned mission timeline. The SA contingency had previously been identified by the operations team as being needful of attention.

Mission Director's Recommendation No. 86: For critical EVA missions, substantial early attention should continue to be devoted to developing and training for contingency procedures. Those procedures that have a reasonable chance of being needed should be accommodated in the EVA timeline.

Another recommendation from Mr. Young was that thorough engineering reviews of HST data be conducted to ensure that the repair timelines are accommodating what the data tells us we will find. Little is presently known about the expected mean time between failures of the HST components.

Mission Director's Recommendation No. 87: Perform a thorough analysis of all available data to understand the probable operational lifetime of HST components. The results of this enhanced analysis could then be used to better schedule component replacement on HST servicing missions.

The Flight Operations Review was held August 3-5, 1993. Results of an analysis were presented which indicated that the HST would likely begin tumbling if a "Norm Z" Orbiter reaction control system configuration were used for the approach to HST within 400 feet of HST. It was also pointed out during the meeting that, given the required budget margins, STS-61 had a negative propellant margin.

On August 6, 1993, Mr. Brewster Shaw chaired a mission status review at JSC for the management of the NASA Office of Space Flight and Office of Space Science. Mr. Shaw assigned a number of action items at the conclusion of the meeting. One action item assigned by Mr. Shaw was the development of a SA mission success plan that would give guidance to make the decision of whether to save or jettison a SA that could not be fully retracted. The plan was later developed which stated that the minimum required effective surface area of a SA was 80 percent. The plan stated that an old SA jammed with less than 80 percent area available would be jettisoned immediately, and one jammed at greater than 80 percent would be saved until the new array was successfully installed. This plan was tested thoroughly in JIS No. 2. Because the flight and ground crews were well trained in this plan, little time was lost when one of the SAs did become jammed during the mission and was subsequently jettisoned.

Another action item assigned was to define IMAX camera in-cabin and crew requirements and crew requirements and crew interference concerns. The amount of IMAX crew training required was assessed by the flight crew and others and determined to not be detrimental to the other, higher priority crew training. It was decided that the STS-61 crew Commander would determine whether IMAX photography would take place during the flight. If he judged that it would interfere with the HST servicing tasks, he had the option to cancel the filming. This procedure worked well during the mission.

Another action item was the definition of EMU gloves and LCVG configuration. The excellent work done to develop and incorporate the improved glove thermal micrometeoroid garment has been cited earlier in this report. Also contributing to crew comfort during STS-61, were improvements in the LCVGs, thermal comfort undergarments, and procedures for cooling control maintenance. An improvement that was available, but which was not used significantly during the mission, was a greatly improved thermal outer glove.

Mr. Shaw called for a review of all DTOs and DSOs for their impact to crew schedules. The STS-61 DTOs, DSOs, and secondary payloads were well managed so they did not interfere with the HST servicing tasks.

Mission Director's Recommendation No. 88: During a Space Shuttle mission, no DTO or DSO should be conducted if it has the potential to hinder the crew's complete accomplishment of the primary tasks.

Mr. Shaw also assigned actions related to crew aid and tool modification configuration control procedures, thermal analyses of Orbiter attitudes, and go/no-go gauges. These issues are discussed elsewhere in this report.

In conjunction with the Mission Status Review, there was held an executive session chaired by the STS-61 Mission Director. The Mission Director presented a number of actions and issues that needed resolution before the launch of HST SM-1. One of these actions was a review of the rationale of the plans to replace only two of the three RSUs, to not fully verify both redundant paths of every system on board the HST, and for SA contingencies. The rationale for these three plans was reviewed and found to be acceptable.

The Mission Director asked for the completion of the development of procedures and timelines for EVA scenarios if there were only one or two EVA days in a shortened mission and for contingency actions for a failed SA retraction. Although valuable procedure and timeline development for the SA contingency did later take place, such development came late in the mission flow.

The Mission Director also called for the development of a detailed alternate plan for crew and ground personnel training, simulations, and holiday and vacation policies to be followed in case the launch were to be slipped to January or later. Such a plan allows for minimization of impact to crew proficiency levels and to personnel and facilities schedules. A plan was developed for crew training and some hardware items.

Mission Director's Recommendation No. 89: For critical missions, especially including Space Station missions, which will likely have only five-minute launch windows, develop detailed crew training and hardware maintenance plans and schedules to be followed in case of a significant launch delay.

The Mission Director asked for the development of a team sleep-shifting plan to maximize the proficiency levels of launch and mission support personnel. Preflight work schedules for flight controllers and some members of management were reduced to allow the personnel to voluntarily adjust their sleep schedules to better be able to support the EVAs, which were conducted in early morning hours. This sleep-shifting was not part of a formal team-wide plan.

Mission Director's Recommendation No. 90: For critical missions that include crew operations scheduled to occur during normal sleep hours, implement a formal plan to facilitate the sleep-shifting of the mission support personnel (including management) before launch.

Another recommendation from the Mission Director was that the portable in-flight landing operations trainer (PILOT) be manifested on STS-61. The PILOT was manifested and was used by the crew, who indicated that it was of value.

Mission Director's Recommendation No. 91: Continue the development and use of the portable in-flight landing operations trainer (PILOT).

The Mission Director also presented the issues of tool fit checks and go/no-go gauges, which are discussed above in connection with Dr. Greenfield's July 29, 1993, report.

During the August 13, 1993, biweekly STS-61 Mission Status Telecon, it was announced that the higher-performance engines designated for use for STS-61 might instead be reallocated for STS-51. It was later decided not to do this, because of their importance to the HST mission. The telecon also included a discussion of a lightning fire at KSC, which was generating smoke near payload handling facilities, which caused concern about possible HST payload contamination.

On August 16, 1993, the HST Project notified STS-61 mission management that it was likely that a task to replace four additional fuses would be added to HST SM-1.

The first STS-61 JIS was conducted August 24-25, 1993. This 36-hour simulated mission timeline included rendezvous with and capture and berthing of the HST, followed by EVA 1. Two of the significant simulated problems were low Orbiter propellant margin and a Flight Support System (FSS) berthing latch malfunction. A number of management issues arose during the JIS that the Mission Director documented as needing the attention of the Customer Management Team and of the Mission Management Team. These issues are discussed below in connection with JIS No. 2.

On August 27, 1993, an HST Flight Techniques Panel meeting was held to perform a safety review of all the HST SM-1 EVA procedures. Although the goal of the meeting was to obtain safety concurrence in all the procedures from the entire EVA community, there was not enough time in a single meeting to address the procedures in sufficient detail to satisfy all the concerns of JSC's crew equipment safety and mission assurance personnel (NS231). The NS231 personnel accepted an action item to perform their own detailed assessment of the procedures and to bring their concerns to the attention of the Flight Techniques Panel. See Mission Director's Recommendations No. 46 and No. 47.

An HST familiarization workshop for the news media was held at JSC August 30-September 1, 1993.

JIS No. 2 was conducted August 31-September 1, 1993. Its timeline included the 38-hour period from the night before EVA 2 through post-EVA 2 HST testing. Among the simulated problems presented were an SA secondary deployment mechanism (SDM) failure, an SA primary deployment mechanism failure to stow, an Orbiter nitrogen tank leakage, and low SA electrical power output. The Mission team performed a jettison of an HST SA. Other EVA accomplishments during the replanned EVA 2 included replacement of one SA, two ECUs, PDU fuse plugs, and SADE-1.

During the first two EVA JISs, there arose a number of management issues, which were documented in a September 29, 1993, memorandum from the Mission Director to the STS-61 Mission Coordination Team. The Mission Director identified the following enhancements as being needed for the remaining JISs and for the mission itself.

a. Clearer delineation of real-time communication and decision-making paths between the Flight Director and HST management
b. Clearer and more timely distribution paths for communicating Mission Management Team (MMT) decisions to the Flight Control Team (FCT) and to the HST Project personnel
c. More proactive participation of the STS-61 Mission Manager and Mission Director in coordinating the resolution of real-time issues between the Flight Director and HST management
d. Clearer definition of HST Project Manager and HST Servicing Mission Manager roles and responsibilities during real-time operations
e. Better utilization and coordination by the HST Project of the Space Telescope Operations and Control Center's (STOCC's) technical support capability
f. Provision of succinct backgrounds and rationales for mission decisions as they were being communicated by the decision makers

In early September, revisions were made to the planned timeline for EVA day 1. On the basis of revised timelines resulting from WETF evaluations, it now was reasonable to perform RSU change-out, solar array carrier preparation, and change-outs of the ECUs and fuse plugs, all during the first EVA.

HTVTs of the thermal modifications to the EMU and of the WF/PC handhold thermal covers were conducted September 10-12, 1993. On the basis of the results of these runs, it was decided that the LCVG bypass modification was not needed for STS-61. This LCVG bypass is discussed more thoroughly in connection with Mission Director's Recommendation No. 85.

In mid-September it was decided by the Orbiter Project Office that all three STS-61 inertial measurement units (IMUs) would be high accuracy inertial navigation system (HAINS) units. This decision was based on the fact that they have a greater mean-time-between-failures prediction than the older design had.

The STS-51 EVA was conducted September 15, 1993. It included evaluations of the EVA thermal environment expected to occur during STS-61, and some of the hardware and tasks planned for STS-61. The STS-51 EVA crewmembers remained thermally comfortable, demonstrating that the newly adopted Orbiter attitude protocol, combined with careful management of the temperature control of the EMU, would also likely keep the STS-61 EVA crewmembers thermally comfortable. The STS-51 crew provided the results of their experiences with STS-61 hardware and procedures to the STS-61 crew.

In mid-September it was determined that the special clips intended to replace the small SADE connector screws were not satisfactory. The small screws would have to be reinstalled after the SADE change-out.

JIS No. 3 was conducted September 28, 1993. It was a ten-hour simulation that included deployment of the HST.

On September 28, 1993, the Flight Requirements Document was revised to add the PILOT DTO and to update the mission priorities.
During the HST flight status telecon on October 1, 1993, it was announced that the RSU change-out tasks would be the first ones performed during the first EVA.

The crew equipment interface test (CEIT) occurred in the Orbiter Processing Facility on October 3, 1993.

The final series of NBS training exercises was conducted October 4-15, 1993. These ten runs offered the EVA crew the first opportunity to train using the RMS II and the Nitrox breathing system. For the first time, the crew was able to perform the EVAs nearly from end-to-end with a high-fidelity RMS simulator. The timelines for EVAs 1-4 were verified for both the scheduled pair of EVA crewmembers and the alternate pair. EVA 5 was not performed during this series. The tasks included in EVA 5 involved smaller hardware items and less critical RMS positioning and could be accurately verified using part task activities in the WETF. Besides these eight nominal procedure runs, the crew also participated in JIS No. 4 on October 8, and performed SA contingencies on October 15, 1993.

JIS No. 4 was conducted on October 8, 1993, the first JIS to be performed with the EVA crew in the NBS at MSFC. This 12-hour JIS included EVA 3. Simulated problems included thermal cover interference during the installation of WF/PC II.

On October 18, 1993, the Stafford HST SM Review Team conducted its final STS-61 review at JSC. The Mission Director presented to them the status of mission preparation. The team expressed satisfaction with the efforts of the team working to accomplish the servicing of the HST.

On October 21-22, 1993, GSFC conducted its internal flight readiness review (FRR). The review board was generally pleased with the level of planning and preparation for mission. The board assigned an action item to the HST Project to reopen a previously closed problem report on the torque output of JSC's mini-power tool. The board was concerned that the higher-than-expected torque produced by the tool could damage the SADE connector screws. In response to such concerns, JSC performed force tests using the tool to install 100 SADE-type screws and demonstrated that the tool would not damage the screws.

On October 27, 1993, STS-61 mission management discussed the first report of significant problems caused by the refurbishment of Launch Pad A. A pipe down-spout immediately outside the payload change-out room had been positioned such that it prevented the opening of the cargo canister. The interfering downspout and others nearby which had been added during the refurbishment were cut away to remove the interference, and the residual pipe openings were plugged and sealed. The use of facilities that have just undergone major changes carries increased risk of such problems. See the next paragraph and Mission Director's Recommendation No. 80.

On October 30, 1993, contamination occurred of the PCR on Launch Pad A. Extensive investigation and planning efforts were initiated to understand the source of contamination, assess the condition of the flight hardware that was exposed to the sand and debris, and develop and implement corrective action. Because it had been double-bagged, most of the payload hardware was not affected, but the ORU carrier (ORUC) and COPE were somewhat contaminated and were successfully recleaned. Sand and debris particles, believed to be residue from sand-blasting operations during the pad refurbishment, had been blown into the PCR by strong winds. The particles are believed to have been on surfaces above the ceiling of the PCR and blown into the PCR through gaps in the ceiling or between the ceiling and walls. Cleaning of surfaces was performed in and around the PCRs of both Pads A and B, in case it was decided to move the Shuttle and payload to Pad B for launch. The seams and gaps in the ceiling and walls of both PCRs were caulked, taped and covered with plastic to ensure no recurrence of the violation of PCR cleanliness. An assessment was made which verified that outgassing of the caulk used would not be detrimental to HST surfaces or materials. It was decided to launch the STS-61 mission from Pad B. See Mission Director's Recommendations No. 79 and No. 80.

At the request of the NASA Administrator, a committee was formed and tasked to provide independent assessment, validation and verification of all the medical aspects of the STS-61 EVAs. The committee was chaired by Capt. E.T. Flynn, the Command Officer of Naval Medical Research and Development. The committee also included other medical experts and experienced EVA astronauts. On November 3-4, 1993, the team conducted its formal review of the STS-61 medical management, EVA plans, EVA history, and current issues. The committee found that the mission plans had adequately addressed the medical risks of the STS-61 mission, and that there was no medical reason not to proceed with the mission.

On November 5, 1993, the Flight Requirements Document was updated (Revision F) to specify the launch date as December 1, 1993.

JIS No. 6 was conducted November 8-10, 1993. It was held before JIS No. 5 due to facilities mission support requirements. JIS No. 6 was a 59-hour JIS, which included EVA 4, EVA 5, and HST deployment. Simulated problems included a HSP stowage problem (requiring the jettisoning of the HSP), an EMU-to-glove disconnect problem (requiring EMU change-out), and an FSS tilt mechanism malfunction. These and other HST and Orbiter simulated problems led to significant EVA replanning and to the holding of the HST on the RMS overnight.

On November 12, 1993, the report by the HST Independent Test Review (ITR) Panel was released, detailing the results of their assessment of the testing and verification performed on the replacement and new hardware to be installed into the HST during STS-61. The panel, led by Dr. Herb Kottler, began its review on October 13, 1993. The panel concluded that the HST Project had developed good test procedures to work around the problems associated with not having the HST available for integration on the ground. They also found that the review and verification process for the mission had worked quite well. They were impressed with the quality and commitment of the people working on the mission, and satisfied that the mission was ready for flight. The panel recommended that future HST servicing missions give a greater amount of attention to the reliability of the HST spacecraft infrastructure (power, attitude control, etc.). The panel also recommended that the HST Project consider improving the onboard diagnostic capability of the HST. The panel recommended that a team be formed to capture the HST SM-1 lessons learned for the next servicing mission team in a living document. The document should include up-to-date detailed test configurations, experience gained in building and testing the servicing hardware, changes in procedures, and translations of STS-61 EVA experience back into hardware design and test guidelines for follow-on servicing missions. The panel also recommended the formation of a multidisciplinary panel to investigate the cost and benefit trade-offs of upgrading the HST simulators.

JIS No. 5 was conducted November 15, 1993. It was a 39-hour simulation that included post-insertion and flight day (FD) 2 activities. During the JIS, the HST was captured while in "safe" mode. The Orbiter was consequently required to be flown through an unplanned roll maneuver to perform the capture.

An ascent and post-insertion JIS was conducted November 16, 1993. Simulated problems forced the Flight Control Team to plan for a reduced-duration flight, with capture of HST on FD 2 and one EVA on FD 3.

The Level I FRR was held November 17, 1993, at KSC. Issues presented during the review as requiring resolution before flight included a cracked seal found in a solid rocket booster auxiliary power unit fuel pump (not scheduled to be flown on STS-61), and damage to the thermal protection system on the external tank used during STS-58. The STS-61 Mission Director presented the status of the recommendations made by twelve different STS-61 review efforts. Of 195 total recommendations, 27 remained to be closed. These open issues were expected to be resolved before the STS-61 L-2 Day review.

On November 19, 1993, the first of several meetings was held dealing with a malfunctioning secondary pressure sensor on the right inboard (RIB) elevon of OV-105 (Endeavour). Under certain unlikely circumstances, the malfunction of this sensor could contribute to degraded flight control of the Orbiter. After assessments were made weighing the risk caused by the removal of this sensor's function against having it function in the wrong manner, it was decided to disconnect the sensor.

On November 21, 1993, interface verification testing with the Shuttle on the launch pad resulted in the Orbiter's acquisition of simulated HST data in an inverted configuration. This problem is discussed above in connection with the January 26, 1993, report of Dr. Greenfield's Program Review Team, and Mission Director's Recommendation No. 61.

On November 29, 1993, a combined L-2 Day and L-1 Day review was held for STS-61 at KSC. Special topics for discussion during the review included the RIB sensor that had malfunctioned and was depinned for the mission. Results of an independent assessment conducted by GSFC of the plans for dealing with the RIB sensor were presented. The assessment resulted in agreement with the risk assessment performed by the Space Shuttle Program and with the Program's chosen course of action. The STS-61 Mission Director reported that all issues raised by the various reviews of the HST SM-1 had successfully been resolved. The Mission Director and the Director of GSFC were polled for their flight readiness concurrence, as were the usual principal managers and organizations. All responded that they were ready to proceed with the mission.

On December 1, 1993, the first launch attempt was canceled due to weather constraint violations. The built-in ten-minute hold at launch minus nine minutes was extended to approximately 45 minutes because of excessive crosswinds (greater than 15 knots) at the Shuttle Landing Facility. The countdown was then continued to the launch minus five minute point to allow for a faster response in case of suddenly improved weather near the end of the launch window. During the extended hold, a cloud cover developed over the launch area, which violated the 8,000-foot minimum required by Range Safety rules. The launch hold continued until the end of the launch window and launch was rescheduled for December 2, 1993.

Mission Events

Launch of STS-61 occurred on December 2, 1993, beginning at 3:26:59.983 AM CST.

During flight day 1 (FD1), mission support personnel were revising the loads analysis for the SA jettison procedures. The prelaunch analysis did not cover the jettison of an SA with the other array still deployed on the telescope. Procedures changes needed to be incorporated to prevent the attached array's being hit by reaction control system (RCS) jet plumes during an Orbiter separation from a discarded array.

During FD2, GSFC personnel worked to resolve a potential conflict in access to the Tracking and Data Relay Satellite System (TDRSS) between NASA and the Department of Defense during the period of the mission in which the grappling of HST was scheduled to occur.

On FD2, the Orbiter cabin pressure was reduced to approximately 10.2 pounds per square inch (psi) as part of the EVA crew's denitrogenation protocol.

Testing of the EMU communications systems revealed noise problems with the EV2 EMU. Trouble-shooting did not identify or correct the problem, but it was believed to be caused by interference from the structural and electrical configuration of the Orbiter airlock and would clear up when the EMU was outside the airlock.

While the crew slept at the end of FD2, ground commands were sent to HST to stow the high-gain antennas (HGAs). Both HGAs were moved to the stowage positions, but did not trigger their "ready-to-latch" indications. Plans were then developed to perform a video survey of the HST after its capture to better understand the failure of the HGAs to completely stow.

On FD3, communication links between the Orbiter and the HST were established without the inverted data problem that occurred during preflight testing.

The HST was grappled by the Orbiter RMS at 2:46:56 AM CST, December 4, 1993.

Visual inspection revealed that the old +V2 SA (attached to the HST) was warped approximately as much as the worst-case analyses had predicted.

After assessment of the video survey of the HGAs and their latch configurations, it was decided to proceed with latch closure. The HGA latches were commanded to be closed. The latch on the +V3 HGA closed successfully. The -V3 latch was able to cage its HGA, but not move it completely to its stowage location. It was determined that this configuration was structurally adequate to withstand a reboost of the HST.

During EMU preparations, it was discovered that two of the four in-suit drink bags (IDBs) were not stowed on the Orbiter. Both of the two bags on board developed leaks during the mission. The crew was able to stop the leaks and the bags were usable.

On FD4, the first HST SM-1 EVA was conducted. The communication with both EMUs was acceptable.

The change-outs of RSU 2 and RSU 3 were successfully performed. The -V3 aft shroud doors could not be closed with the first attempts, and it was decided that the EVA crewmembers would proceed with other tasks and would finish the closing of the doors later in the EVA.

Some solar array carrier (SAC) preparation work was performed in parallel with the ECU replacement tasks. Replacements of ECU 1 and ECU 3 were successfully performed.

During the change-out of the fuse plugs, the crew noticed a different configuration of J-hook pass-through than that expected before flight. The fuse plug change-outs were successfully performed.

The -V3 aft shroud doors were eventually closed with the aid of a payload retention device (PRD) strap and the efforts of both EVA crewmembers.

Following the EVA tasks, the -V2 SA was successfully retracted, but only after repeated commands were transmitted. The +V2 SA retraction was stopped when the crew saw the SA blanket becoming slack as the damaged area of bistem reached the cassette. It was decided not to make further attempts to retract it, but to jettison it during EVA 2.

During the overnight planning for EVA 2, there was some uncertainty concerning whether the disconnection of the SA diode boxes needed to occur during nighttime so that electrical current from them would be minimized. For this reason it was decided that nighttime disconnection would be performed (i.e., with no light shining on the SAs from either the sun or the earth).

During the airlock depressurization, the feedwater switch on the EV3 crewmember's EMU was found to have been bumped "on" prematurely, which, in the worst case, would cause the EMU cooling system to not function. The crew turned the switch "off" and waited a sufficient time before turning it back "on" for the EMU to then function properly.

At the start of EVA 2, the EV3 crewmember could not hear radio communication from either the Orbiter or the ground, but only from the EV4 crewmember. It was decided to conduct the EVA having EV4 relay Orbiter and ground communications to EV3. This relaying of communications was allowed by flight rules, and worked well during the execution of the EVA.

After the +V2 SA was removed, EV3 performed a manual release of it while attached to the extended RMS. The Orbiter then performed an RCS four-pulse Low-Z separation burn, followed by a sixteen-pulse Norm-Z separation burn, which would normally impart a one foot-per-second separation rate. After the SA was hit by the plume of the Norm-Z firings, however, it was estimated that the rate of separation was four feet per second. During the Norm-Z firings, the GHRS instrumentation registered a pressure spike, indicating the presence of gas inside the HST.

The new SAs were successfully installed during the EVA.

The first task performed during EVA 3 was the successful change-out of the WF/PC.

One of the HST power tools stopped working during the EVA.

The two magnetic sensing system (MSS) modifications were also successfully installed during EVA 3. During the installation, two metal plates that were part of the protective cover of MSS 1 were found to be loose and were removed by the EVA crew. The primary heater on the old MSS 2 was reported to have failed.

Discussions occurred during the EVA concerning what tasks might be added to the end of EVA 3, since the crewmembers were considerably ahead of schedule. The GHRS redundancy kit was being considered as an added task. However, it was decided that only simple tasks in preparation for the next day's EVAs would be performed.

After EVA 3, considerable planning by the ground support team took place concerning the need to re-cover MSS-1 to limit further degradation of the foam from exposure to sunlight and atomic oxygen. A plan was developed calling for the EVA crewmembers to retrieve pieces of multi-layer insulation (MLI) from the payload bay during EVA 4. Some of this MLI would be used to fabricate new covers for both MSS units.

The HSP removal, and successful COSTAR and coprocessor installation all occurred during EVA 4. No significant problems occurred related to these operations.

The EVA crewmembers were initially told to retrieve MLI only from the two radial scientific instrument protective enclosure (RSIPE) "A" latch releases, but were later told to also remove the MLI from the two WF/PC handle fixtures. The crew brought all four MLI pieces into the cabin.

After EVA 4, the mission support team worked to resolve an apparent data problem. During the analysis of data related to this problem, suspicions were raised about the health of the memory of the coprocessor. Discussions were held about the possible replacement of the DF-224 computer, in case a coprocessor problem had also corrupted the original DF-224. It was eventually decided that if a coprocessor problem were to be verified, then the coprocessor would be disconnected electrically from the DF-224, and both would remain in the HST. The data problem was later determined to be a communications problem unrelated to the HST.

The reboost occurred early on FD8 and was terminated by the crew when the Orbiter trajectory was taking longer than expected to totally match the target trajectory. Instead of a resulting circular orbit of 321 nautical miles, the final orbit was approximately 321 by 320 nautical miles. The STS-61 Lead Flight Director has commented that similar burns in the future should be terminated based on a velocity target in the Orbiter "X" direction only. During the reboost, the crew was surprised by the amount of relative motion between the HST and the Orbiter. However, this relative motion was within the range predicted by preflight analyses.

The SA primary deployment mechanisms (PDMs) failed to move when commanded to do so before EVA 5. It was decided that the crew would perform the SADE change-out while ground personnel would work on plans for SA PDM deployment contingency procedures.

During the successful SADE change-out, four of the small connector screws were lost, but each of the eight connectors was secured with at least one screw, and only one screw is needed for adequate attachment.

The EVA crewmembers were able to manually deploy the SA PDMs.

The EVA crewmembers also successfully installed the GHRS redundancy kit during EVA 5.

The EVA crew then installed the newly fabricated MLI covers onto both MSSs.

While the EVA crewmembers were doing their final payload bay clean-up procedures, both SAs were successfully deployed.

Additional data problems were encountered following EVA 5, which were eventually attributed to a problem with a data interface unit no. 2 (DIU 2) side A in the HST. The DIU was switched to side B, which functioned properly.

On FD9, HST was grappled, unberthed, and held by the RMS while the aperture door was opened. At 4:26:47 AM CST, the HST was released from the RMS.

The crew was given a day off on FD10.

On FD11, the Commander and Pilot used the portable in-flight landing operations trainer to practice Orbiter approaches and landings.

Because weather at KSC was predicted to deteriorate near the originally planned landing time, it was decided to deorbit on orbit number 162, one earlier than scheduled. Endeavour's wheels stopped rolling after landing December 12, 1993, at 11:25:35 PM CST, with a mission elapsed time of 10 days, 19 hours, 58 minutes, and 35 seconds.

Appendices to the

STS-61 Mission Director's

Post-Mission Report

Appendix A

Mission Director's Recommendations

1. EVA tasks requiring precise handling of medium and large masses should be rehearsed on orbit to the extent possible. Tasks involving small, difficult-to-handle objects such as noncaptive screws should also be practiced on orbit.

2. Every effort should be made to completely understand and to be able to duplicate on the ground the configuration of hardware that is on orbit. Methods that can be used to help achieve this capability include detailed records (including photo documentation and accurate engineering drawings, both made of the as-deployed configuration), molds of the interfaces, accurate tooling representing mating interfaces, etc. Such a capability to duplicate on earth what exists in orbit should be considered an initial design requirement for on-orbit hardware.

3. The Space Station Program should develop and maintain a detailed three-dimensional computer model of the planned Station configuration similar to Orbiter models maintained in the PLAID and Integrated Graphics Operations and Analysis Laboratory (IGOAL) systems at JSC. The model should be made easy to update as design changes are made. It should be accessible by the Space Station community of designers, customers, and operators. It should be maintained as an as-built model of the station during and after the assembly phase.

4. For critical and high-interest NASA missions, a thorough public-relations strategic plan should be implemented. It should be well coordinated among all involved NASA offices. A single NASA office should be in charge of the implementation and updating of the plan at all NASA centers and any other key sites (vendor facilities, etc.). Mission success criteria should be generated by mission management early in mission planning and provided to the press by the public-affairs organization(s). A contingency plan of action in response to mission "failure" should be in place and announced before the mission. Information at all levels of detail should be readily available to the press. The mission's importance should not be overstated, and its complexity should not be understated.

5. Design all critical missions so that maximum possible mission duration is incorporated at the inception of mission planning. Early development of mission requirements is necessary. If needed to provide adequate margins, an Orbiter with increased-duration modifications should be used for the mission.

6. To ensure that timeline margin exists for each EVA day, continue to plan tasks for an EVA so that they will take no longer than six hours to complete.

7. Analyze future HST and Space Station EVAs, both scheduled and contingency, to determine whether three-crewmember EVA capability would be desirable. If so, modify the Orbiter air-locks, Shuttle extravehicular mobility units (EMUs), and training facilities to accommodate three-crewmember EVAs. The modifications should include a third air-lock-to-EMU umbilical connection, an EVA radio capable of three-channel operation, and other changes as appropriate.

8. Flight hardware (including tool) operations and interfaces should be verified as early as possible before flight, in worst-case thermal vacuum conditions to the extent possible.

9. EVA crewmembers scheduled to perform EVA tasks in severe thermal conditions should experience those conditions in their flight EMUs (or equivalent) in vacuum chamber testing before their flight.

10. NASA should expand its efforts to evaluate all new hardware, untried procedures, and thermal effects of new Orbiter attitudes, during missions before the missions for which they are required. Development of mission requirements is needed as early as possible to allow time to support these earlier missions. For HST servicing missions, the HST Project organization should develop the plan to exercise tasks and hardware as early as possible. The Space Station Program should closely analyze EVA thermal environments (especially those which will exist while an Orbiter is attached to the Station) to ensure adequate EVA thermal capability.

11. Designs of all hardware having the potential to be attached to or removed from other hardware during EVA should be thoroughly assessed for adequate temperature and vacuum tolerances. Past flight experience and the knowledge base of previous EVA designers should be used in this assessment. See also Mission Director's Recommendation No. 8.

12. Critical EVA tasks should be designed so that they can be fully accomplished if there were total loss of the use of the RMS.

13. The Space Shuttle Program should thoroughly assess the feasibility of manual capture and berthing of the HST. If determined to be feasible, such procedures should be developed and future HST servicing mission EVA crews should be trained to perform them.

14. For EVA missions, select the Payload Commander, the EVA crew, and the Capcom as early as possible.

15. For complex EVA missions, perform flight production milestones earlier than in the standard template. For the second HST servicing mission, consider the following template.

EVENT	MONTHS BEFORE FLIGHT
Selection of Payload Commander and EVA crew*	24
Baselining of Flight Definition and Requirements Directive	20
Cargo Integration Review	15
Flight Planning and Stowage Review	11
Flight Operations Review	4

Other mission milestones should be moved earlier proportionately.

* For missions requiring close coordination among the commander, pilot, RMS operator(s) and EVA crew, consideration should be given to selecting the entire crew at this time.

16. Use EVA-experienced flight crewmembers, preferably the Payload Commander and other EVA crewmember(s) who are assigned to the mission, to help develop and evaluate critical EVA hardware, tasks, and procedures.

17. To the extent possible, assign an EVA-flight-experienced Commander and Capcom to critical EVA missions.

18. To increase margins for the success of the Space Station assembly, determine the tasks required for assembly and the number of crewmembers required to perform them. Use EVAs on prior Space Shuttle missions to practice those

tasks and to provide EVA experience to as many different astronauts as possible.

19. For critical EVA missions, select EVA crewmembers so that the required EVA tasks can still be fully accomplished if either a crewmember or an EMU becomes unable to support an EVA.

20. Establish a formal human factors assessment effort to identify and facilitate improvements to generic EVA capabilities and hardware and to enhance EVA procedures as required for specific EVA tasks. This responsibility might best be assigned to the newly formed EVA and Crew Equipment Project Office.

21. Continue the practice of having all mission support personnel, including management and especially customer management, participate in joint integrated simulations (JISs) for critical missions. JISs for scheduled EVAs should be conducted with EVA crewmembers in underwater training facilities, unless facility or mock-up limitations prevent the crew from performing realistic activities.

22. For critical missions, the Mission Operations Directorate should develop more clearly defined and detailed training objectives for the JISs for flight controllers, flight directors, and mission and customer management. Post-JIS reports should be distributed to the JIS participants detailing these objectives and how well they were achieved. Corrective actions should be assigned and lessons learned should be formulated and distributed.

23. For HST servicing missions, continue the practice of conducting HST Project internal simulations. They should be well structured and the results should be well documented.

24. The Space Station Program should assess the benefits of performing internal simulations prior to the JISs for Space Station assembly. If determined to be of value, they should be well structured, with clear training objectives, and the results should be documented distributed to the participants. Objectives should include the definition and exercising of the relationship between the Launch Package Teams and the Flight Control Team during both nominal and contingency operations.

25. The Mission Operations Directorate should assess the methods used to access payload technical data, drawings, and photographs during the STS-61 simulations and during the STS-61 mission. Corrective actions should be implemented to eliminate all identified problems. Work should continue on improvement of storage and retrieval efficiencies. See Mission Director's Recommendations No. 41 and No. 71.

26. **The Space Station Program should consider the development of a top-level fault-tree analysis.**

27. **Consider the implementation of an overall training facilities requirements control document for future HST servicing missions. It should define, as early as possible, the testing and training to be done at the various training facilities (vendors, High Fidelity Mechanical Simulator [HFMS], KSC, WETF, Neutral Buoyancy Simulator [NBS], et al.)**

28. **The Space Shuttle Program should perform a complete assessment of the results of the HST SM-1 mission relating to potential sources of contamination. The results of this assessment should then be provided to all payload owners, including the HST Project, and the Space Station Program. Review crew comments, indications of pressure spikes inside the HST, and films and videotape made during the mission (including IMAX film of EVAs and videotapes made during the opening of the payload bay doors).**

29. **The HST Project should examine returned components removed from HST for indications of previous contamination and of material deterioration that would indicate the potential for generation of contamination by similar materials still on orbit. These results should be incorporated into the Space Shuttle Program's assessment discussed in Mission Director's Recommendation No. 28.**

30. **The Space Shuttle Program should develop and publish data indicating temperature ranges and locations within the payload bay that should be avoided by payloads sensitive to vapor or condensation of Orbiter supply water, waste water, flash evaporator system water, reaction control system (RCS) jet combustion products, and leaking RCS propellants.**

31. **Continue to provide to EVA astronauts clear and detailed training in what, if any, items in or near the EVA work areas should not be touched by them. These items should be represented by mock-ups during training to ensure that EVA procedures can be accomplished without contact with the "no-touch" zones.**

32. **For as long as the HST is in service, the HST Project should use strict configuration control to maintain the fidelity of their High-Fidelity Mechanical Simulator.**

33. **For both the Space Shuttle and the Space Station Programs, continue and expand the efforts to make training mock-ups that are dimensionally as flight-like as possible. Be alert to any differences between training and flight hardware and incorporate the necessary precautions into the training plan to avoid negative training. Take precautions to prevent damage from handling, shipping, etc., and deterioration from corrosion, inadequate maintenance, etc.**

34. **Develop and verify the adequacy of a multi-layer insulation (MLI) repair kit for future HST servicing missions. It should enable EVA astronauts to repair the black MLI inside the telescope cavities and the MLI external to the telescope and to repair light leaks resulting either from micrometeoroid or other damage to the telescope or from poorly fitting doors or light seals.**

35. **Reassess the feasibility of developing a method for detecting light leaks in the HST during future servicing missions.**

36. **For complex missions a management plan should be developed early in the planning flow. The development and execution of the plan should be coordinated among the various elements of the mission team.**

37. **For critical missions, including HST servicing and Space Station assembly and maintenance missions, a multidisciplinary team should be established to provide a thorough and comprehensive independent assessment of flight readiness. The team should identify areas of potential risk and make recommendations of appropriate actions to enhance mission success.**

    The team must possess a relevant experience base. The team leader and panel chairs must possess broad program experience. The core team members should be selected for applicable technical background and mission experience, including EVA experience from a similar mission or membership in a previous similar assessment effort. The team should identify and use a large pool of independent experts, both internal and external to NASA in all key areas. It should plan for sub-panel assessment activities to be led or coordinated by a core member of the team.

    There should be established a good understanding of, and agreement on, the team's objectives, approach, and schedule, among the team, mission management, payload (e.g., Space Station) and Space Shuttle program management, and contractors. The team should establish close and on-going interaction with the mission team management. A Mission Director, if assigned, should be the overall focal point for interface and should establish the process for contractor interface. The team should establish a formal process for working with the mission team, using an informal working relationship but maintaining a formal response and action process.

    The team's effort should begin with payload hardware design reviews and continue until launch. The team should develop a plan of action and milestones for team effort based on established funding. It should optimize its level of effort for available funding and carefully track costs. The team should strive to minimize disruption by scheduling their reviews in coordination with established events and milestones for mission hardware, for Space Shuttle Program (SSP) mission preparation milestones, and center and Headquarters reviews. Their readiness review effort should be expanded

for critical design review and test readiness reviews. A small sub-panel of technical experts should participate in hardware reviews. Their expertise should include EVA experience as appropriate. Their effort should focus on design, testing, interfaces, fit, and processing. The team's effort should again be expanded for mission planning and mission preparation activities. The team should influence mission operation plans and contingencies.

The team should make extensive use of lessons learned data bases from related activities. It should make extensive use of available data and individual team members should conduct reviews prior to the collective assessment effort in order to minimize travel.

It should conduct an independent assessment of the flight worthiness of the design, the fabrication and testing, and the integration and preparation of the mission hardware, software, and supporting systems. The team's review should assess exceptions to performance and build norms, analyze waivers and deviations, review failures and their resolutions, and assess payload hardware-to-Orbiter interfaces. The team should also review preflight planning activities, training and simulation plans, and mission plans. The mission management should be reviewed regarding structure, processes, responsiveness, and effectiveness. The team should assess closure of anomalies and management response to review team issues and recommendations.

38. Establish nighttime Shuttle training aircraft (STA) training requirements for the commanders and pilots of all Space Shuttle missions. This is especially critical for missions scheduled to land at night and for ground-up rendezvous missions, which have the potential for landing at night, depending on when they are launched. Establish requirements for demonstrated minimum performance levels for night landings.

39. To help ensure efficient and successful planning and execution of complex EVA missions, it is important that EVA task priorities be established as early as possible, preferably well before the standard time of publication of the Payload Integration Plan, and before the occurrence of the Cargo Integration Review.

40. Scheduling of critical EVAs before flight day four should be done only for missions whose critical crewmembers have an established history of being free of Space Adaptation Syndrome symptoms by the flight day of the EVA, and should be done only with the concurrence of the crew and the flight surgeon, based on a thorough analysis of pre-EVA activities and timelines.

41. For the future HST servicing missions, as well as for all other critical EVA missions, including Space Station assembly and maintenance missions, it is

important to develop comprehensive collections of photography (including videotape and digital imagery) of the flight hardware, organized in a manner that will support timely analysis and troubleshooting. To the extent possible, plan to make a complete photographic record of the prelaunch and on-orbit configurations of deployed hardware to help ensure that future mission planning will be based on accurate data. Imagery data should be maintained in a readily accessible, rapid-retrieval system. See Mission Director's Recommendations No. 25 and No. 71.

42. To provide clearer decision-making guidelines for matters involving crew activity constraints, the authority to waive constraints in Appendix K of the Space Shuttle Crew Procedures Management Plan should be clearly defined.

43. For critical EVA tools and batteries, ensure that ample in-flight backups are available. If the use of power tools is essential to the completion of required tasks, fly enough tools and batteries to accommodate multiple failures of each.

44. Review the performance of the batteries used during the STS-61 EVAs. Assess the adequacy of the strategy used to manifest the types and quantities of the batteries that were flown. Compare the STS-61 battery plan to other techniques and technologies, including in-flight recharging, and other types of batteries.

45. Investigate alternatives or improvements to the present foot restraint concept, to enable an EVA crewmember to be secured at worksites for which the present foot restraints are not satisfactory.

46. For each NASA human space mission, designate a single point of contact who is directly responsible for coordinating the entire safety and mission assurance effort for the mission (including hardware, systems, and operations).

47. NASA should develop a single process that is responsible for all aspects of EVA safety and mission assurance (S&MA). This process should assess the integrated EVA-related S&MA aspects of flight crew equipment, other government-furnished equipment, payload-related hardware, and EVA, Orbiter, and payload operations.

48. A mission director should be appointed for future HST servicing missions and other highly complex space flights designated by the NASA Administrator. The mission director should be responsible for the management direction and oversight of the integration and flight preparation process and accomplishment of the mission. The mission director's responsibilities should include oversight of the mission training and concurrence in the determination of the flight readiness of the flight crew, the

integrated operations team, the customer management team, and the mission management personnel. The mission director should provide concurrence in the date and time of launch, and the launch window. The mission director should also concur in the mission goals, objectives, priorities, and policies. The mission director should participate and concur in the selection of the crew. The mission director should be responsible for the proper coordination among the various NASA offices, NASA centers, NASA program managers, and persons, groups, and organizations external to NASA who have a responsibility for the safe and successful execution of the mission. The mission director should establish special committees and/or assessment teams, as required, to assess the readiness of the STS and cargo to support mission requirements. The mission director should have final approval authority of the cargo mix, including secondary payloads, detailed test objectives (DTOs), and detailed supplementary objectives (DSOs). The mission director should be responsible for the resolution of key issues involving any aspect of the mission. The mission director should co-chair the Mission Management Team (MMT). The mission director should be responsible for ensuring that the Space Transportation System (STS) and cargo comply with all safety requirements. The mission director should be responsible for mission assurance and flight readiness of the STS and cargo, and provide concurrence in resolutions of payload or Orbiter anomalies that have a potential impact on mission success. The mission director should be a signatory on certificates of flight readiness that pertain to the specific flight for which the director has responsibility. The mission director should provide concurrence in the approval or disapproval of flight specific waivers. The mission director should represent and report directly to the Associate Administrator for Space Flight.

49. The Space Shuttle Program should formalize its various lessons-learned databases and make them widely available to the Shuttle customer and design communities. The EVA and Crew Equipment Project Office might be the proper owner of the EVA and RMS lessons databases.

50. NASA should complete the development of a NASA-wide and interagency database of lessons learned from aerospace programs. The input of data into the database should be made a requirement for government aerospace programs. The database should be well publicized and easily accessible to NASA program and project managers.

51. Expand and use state-of-the-art EVA tools and training methods (such as RMS II presently installed at MSFC's NBS, Nitrox, virtual reality, improved air-bearing techniques, et al.) to perform training and EVA tasks with maximum efficiency. Investigate other potential sources of ideas for improvements, including time-motion studies and the experiences and techniques of the Russian space program. Especially consider improvements in the area of

thermal protection of the EVA crewmembers, assessing the desirability of devices such as hand warmers and an EVA infrared temperature sensor.

52. Fund and develop a fully integrated EVA training facility (such as the proposed JSC Neutral Buoyancy Laboratory [NBL]), which would incorporate a large capacity pool, state-of-the-art RMS simulator, Nitrox, flight-like video and audio communication capabilities, and any other features useful to provide the flight crew and flight controllers the best possible end-to-end EVA training.

53. For Space Station EVAs and for other EVAs with worksites too large to fit into underwater training facilities, develop alternate training method(s) that will accomplish reliable end-to-end timeline quantification and crew training. Consider the use of virtual reality to provide three-dimensional training for handling large masses and to develop methods of translating objects that cannot be simulated in water-training facilities.

54. For EVA flight crews, develop and provide training EMUs that have flight-like stiffness.

55. To minimize negative EVA training, continue to quantify shortcomings of training facilities and to make sure that the differences between the training and flight environments are well understood by the flight crew. Work to eliminate these differences where possible. Also, where possible, provide alternate part-task training to compensate for facility shortcomings. Maximize the repeated exposure of actual flight hardware to the crew throughout their training.

56. Continue the refinement of the strength and conditioning program in which STS-61 EVA crewmembers participated. Implement this program as a requirement for all assigned EVA crewmembers.

57. The Space Shuttle Program should review the current launch criteria and procedures and incorporate changes that would safely enhance the likelihood of supporting the expected requirement for a five-minute launch window for Space Station missions.

58. Shuttle consumables reserved for Orbiter contingency EVAs should not be reallocated for any other purposes.

59. For HST servicing missions and for Space Station missions, continue to achieve the proper balance of payload commanding performed from the ground and performed by the flight crew. To the extent practical, maximize the amount of commanding which can be performed by the flight crew, to avoid delays caused by waiting for a good air-to-ground communications

link. Thoroughly rehearse and evaluate the commanding protocols during joint integrated simulations.

60. Continue to maximize the amount of end-to-end communications and commanding testing performed before critical missions.

61. For the next HST servicing mission, fully understand the potential for acquiring inverted data from the HST. If the capability for in-flight rewiring is determined to be necessary, make the necessary preflight modifications to Orbiter equipment to allow the crew to perform this action with minimal effort (e.g., operating a simple switch).

62. Identify requirements for joint center operations as early as possible in the mission flow to allow time to resolve technical, budgetary, and administrative issues without causing impacts to mission schedules.

63. The Space Station Program should thoroughly assess requirements for integrated RMS/EVA training in comparison to available facilities. If it is determined that facilities at other centers are required (e.g., MSFC's Neutral Buoyancy Simulator), necessary intercenter agreements should be established as soon as possible to ensure availability and proper configuration of facilities.

64. For HST servicing missions and for critical Space Station assembly missions, NASA should consider designating a crewmember to serve as both EVA Capcom and backup EVA crewmember.

65. Maximize communication among all organizations supporting critical missions, both before and during the missions, to minimize wasted effort and inaccurate data. This communication can be facilitated by periodic technical interchange meetings and by regular management meetings similar to the biweekly STS-61 mission status telecons conducted by the Mission Manager. Also maximize use of electronic systems for the transfer of verbal and graphical communications, including photographs and engineering drawings, among the entire mission team.

66. Establish a single NASA-wide set of underwater diving requirements (dive tables).

67. For critical EVA missions, continue to maximize the amount of preflight experience the EVA crew receives with the actual flight hardware.

68. For the second and subsequent HST servicing missions, mission planners should again develop a list of primary tasks, which would trigger a contingency mission if not completed.

69. To the extent possible, critical EVA mission timelines should be arranged such that at the completion of each EVA day, the payload (or Space Station) is in the best possible configuration to be left in, in case the Orbiter must deorbit before the next EVA.

70. Perform sufficient failure analysis of returned HST components to ensure that failure causes are understood. Also look for signs of degradation other than those which caused the failures.

71. The Mission Operations Directorate should develop a computerized system to support decision making during real-time EVA mission replanning. The system should provide the flight team with access to information related to the EVA timeline and procedures; tool histories, performance capabilities, and locations; and payload configuration. It should also provide access to photographs and engineering drawings. See Mission Director's Recommendations No. 25 and No. 41.

72. To the extent practical, expose the participants of joint integrated simulations to all the nominal mission activities.

73. Reassess the rationale for not verifying the redundancy of all HST systems, now that the telescope has been serviced. Consider verifying the function of redundant elements whose health is not now known, where such verification would not risk the health of the HST. This verification should be performed early enough to allow replanning of the second servicing mission, should components be in need of replacement.

74. Prior to critical missions, especially the HST servicing missions and Space Station Assembly missions, perform detailed thermal analysis and modeling to verify that crewmembers and hardware are not subjected to temperatures beyond their functional limits. Beta angle of the mission's orbital plane(s) should be included in the analysis. This analysis for the Space Station's worst-case altitude, inclination, attitude, configuration, and beta angle should be performed as soon as possible. See also Mission Director's Recommendation No. 10.

75. EVA hardware, including all tools, supplied by multiple NASA organizations should be manufactured to standardized NASA-wide certification requirements, and be controlled by a single configuration control board. Performance verification (including fit checks and verification of thermal tolerance) requirements should likewise be standardized.

76. Technical information, including certification data, related to flight tools and other EVA hardware, should be maintained in a rapidly accessible format to support replanning and failure assessments during missions.

77. Verify that the hardware and software to be used for critical mission operations are not to be used outside the operational ranges for which they were certified. Also verify that the certification requirements used for this hardware and software are consistent with current program certification guidelines.

78. For HST servicing missions and all other missions having payloads sensitive to contamination, specify any purge purity requirements early enough in the mission processing flow to allow for verification of the capability to comply with those requirements. Consider the use of special ground servicing equipment (e.g., JPL's purge purification equipment) to meet requirements too stringent to be met with standard equipment.

79. For HST servicing missions and all other missions having payloads sensitive to contamination, have in place at the launch site a comprehensive plan to protect the payloads from all sources of contamination, including human-generated and natural sources.

80. For critical or sensitive missions, minimize the number of any untried or unusual mission preparation activities (e.g., launch pad refurbishment) or flight activities that do not serve to increase chances of mission success.

81. Conduct an independent assessment of the contamination control procedures performed at KSC for STS-61. Assess them for adequacy for the second HST servicing mission. Verify implementation of corrective action to prevent recurrence of wind-blown contamination of the Payload Change-out Room, or any other payload processing facility.

82. Continue the practice of not scheduling EVA crewmembers to perform EVAs on consecutive days. Exceptions should be allowed only on a contingency basis, with the concurrence of the crew, the flight surgeon, and the mission management team.

83. Establish a single NASA-wide set of standards for the definition of payload command and data parameters.

84. Continue to develop EVA methods to remove jammed mechanisms and bolts. Design goals should include the capability to impart large forces to the jammed mechanisms or bolts, while transferring little force to payloads or other structures.

85. Complete the design of and incorporate the liquid cooling and ventilation garment (LCVG) bypass into EMUs to be used during potentially cold EVAs during critical missions.

86. For critical EVA missions, substantial early attention should continue to be devoted to developing and training for contingency procedures. Those procedures that have a reasonable chance of being needed should be accommodated in the EVA timeline.

87. Perform a thorough analysis of all available data to understand the probable operational lifetime of HST components. The results of this enhanced analysis could then be used to better schedule component replacement on HST servicing missions.

88. During a Space Shuttle mission, no DTO or DSO should be conducted if it has the potential to hinder the crew's complete accomplishment of the primary tasks.

89. For critical missions, especially including Space Station missions, which will likely have only five-minute launch windows, develop detailed crew training and hardware maintenance plans and schedules to be followed in case of a significant launch delay.

90. For critical missions that include crew operations scheduled to occur during normal sleep hours, implement a formal plan to facilitate the sleep-shifting of the mission support personnel (including management) before launch.

91. Continue the development and use of the portable in-flight landing operations trainer (PILOT).

Appendix B

Payload Officers Recommendations

The following list of recommendations is excerpted from the Mission Operations Directorate's STS-61 Payload Officer Mission Report, written by the Payloads Support Operations Section of the Mission Operations Directorate of the Johnson Space Center.

A. Mission Planning and Preparation

1. We recommend that no significant change be made to the Servicing Mission Operations Concept in the areas of MCC [Mission Control Center]/STOCC [Space Telescope Operations and Control Center] interfaces for subsequent missions.

2. We recommend that an extended shift overlap be exercised on future EVA-intensive missions involving integrated crew/ground command activity.

3. We recommend that future missions define the working relationship between the FCT and customer EVA cadre early and train/debrief it often to allow it to become habit for the integrated team.

   The Mission Director agrees. See Mission Director's Recommendations No. 21, No. 22 and No. 23.

4. We recommend that a) priority be given to the early development of EVA contingency documentation, and b) any trend toward off-line contingency planning during EVA or other critical mission phases be discouraged.

   The Mission Director agrees. See Mission Director's Recommendation No. 86.

5. The EVA Working Group splinter to the HST Servicing Mission POWG forum should be maintained in the planning of future servicing missions.

6. We encourage the project to continue the SMOWG [Servicing Mission Operations Working Group] forum for future servicing missions.

7. We recommend that the flight director office continue the practice of providing regular opportunities for internal MOD tag-up meetings in the planning of complex missions that require new and innovative ways of doing business.

8. We recommend that complex missions perform a similar dry run FOR process as part of the POWG forum during the months preceding the actual FOR to improve the effectiveness of the FOR process.

9. We recommend that long duration simulations spanning multiple shifts be utilized as often as possible for complex missions, with a minimum of two such sims to allow team performance problems to be identified and resolved.

   The Mission Director agrees. See Mission Director's Recommendations No. 21, No. 22 and No. 72.

10. We recommend that future sim scripts include systems anomalies to be dealt with by the planning team in parallel to performing the replan function.

11. We recommend that future missions take advantage of any early training opportunities to work out communications problems between centers prior to the first JIS.

    The Mission Director agrees.

12. We recommend that a JSC training counterpart become involved in GSFC internal sim planning at the outset and provide coordination of simulated anomalies, and simulated air-to-ground interchange. If this cannot be achieved, then at a minimum the GSFC sim director should pre-brief the JSC team on the anomalies he intends for us to report or respond to so that we can "fake it" better.

    The Mission Director agrees.

13. We recommend that the GSFC sim team include more SSE-related material in future internal sim scripts.

14. We recommend that future training plans incorporate early opportunities to include the integrated EVA team, with scripting that takes advantage of their participation.

15. We recommend that high priority be given to contingency planning for any complex or high priority mission well in advance of the FOR.

    The Mission Director agrees. See Mission Director's Recommendation No. 86.

23. We recommend that future servicing missions continue [to provide] the crew with the ability to proceed with EVA servicing with a minimum of ground interaction, if necessary.

    The Mission Director agrees. See Mission Director's Recommendation No. 59.

24. Future missions should consider carefully whether an FDA on any given measurement is required. If no crew action is driven by an indication, then don't FDA the parameter unless requested to do so by the flight crew.

25. We recommend that the PLAIDS model of HST be maintained and upgraded, as required, to support future servicing mission planning.

    The Mission Director agrees.

26. We also recommend that the practice of performing an independent verification of PLAIDS results using the RSOC [Rockwell Space Operations Contractor] clearance analysis tool be continued.

B. <u>HST Operations</u>

1. Additional effort should be given to documenting the materials and construction of the HST components for future missions. The information should be readily available during flight to help plan and react to possible EVA scenarios.

   The Mission Director agrees. See Mission Director's Recommendations No. 2, No. 25, No. 41, and No. 71.

2. We recommend a broader distribution of engineering test results by the sponsoring organization among the operations community in the POWG or Flight Techniques Panel forums, with emphasis on operations impacts resulting from test anomalies and work-arounds.

   The Mission Director agrees.

16. We recommend that, for payload comm-intensive missions, the lead Payload Officer draft a memo to the lead INCO [Instrumentation and Communications Officer] prior to the Flight Operations Review that summarizes the mission-unique communications configurations and requirements for the INCO team. We believe that this will assist the INCO team in reviewing the FOR data package and preparing for start of simulations.

17. We recommend that the INCO comm plan be briefed at the mission-specific Flight Techniques Panel prior to start of simulations, and the INCO Comm Management memo be distributed well in advance of flight.

    The Mission Director agrees.

18. We recommend that a multidisciplinary team from MOD (including payload operations, flight planning, GNC [guidance, navigation and control] and RMS), Cargo Integration, and Engineering Directorate (including Draper) be formed to study suggested improvements in how coupled loads analyses are planned, implemented, and disseminated to the operations community. A debrief of the GSFC and Swales personnel involved in STS-61 should be included in this assessment.

    The Mission Director agrees.

19. Future spacecraft that rely on the Orbiter for repeated visits should be designed for compatibility with the Orbiter payload communications system.

20. We see no significant value in pursuing additional PSP [payload signal processor] bypass testing in an effort to understand how the PI works in this configuration, which has always been considered outside its specification. We have a system that works, and have work-arounds defined should an inversion occur.

    See Mission Director's Recommendation No. 61.

21. We recommend that a team from GSFC and JSC be formed to develop methods and/or tools that will prevent misunderstandings on parameter definition in the Command and Data Annex on future missions.

    The Mission Director agrees. See Mission Director's Recommendation No. 83.

22. We recommend that a formal SAIL test be performed on payload GPC displays using a payload-provided telemetry tape at the earliest opportunity subsequent to engineering cycle release, and that customer personnel support this test and participate in identifying and closing out discrepancies.

3. We recommend that, in the absence of any network or Orbiter hardware changes that will reliably alleviate the problem with transmitting 4 kbps DF-224 memory dump data on Ku-band channel 2, future missions be planned such that ...

   1) DF-224 computer dumps be performed direct via TDRSS, or
   2) the project assess the feasibility of a 32 kbps memory dump format that will allow dumping of the HST computer via the Orbiter PDI [payload data interleaver].

4. Present predictions indicate that a reboost will be required on the next servicing mission, which in turn will require the SAs to be fully retracted and latched to the side of the spacecraft. It is also believed that an STOCC-commanded PDM stow is unlikely based on the following STS-61 flight experience:

   1) The switch guards would most probably interfere with a full PDM stow, and
   2) During -V2 SDM retraction, the solar array deployment mechanism [SADM] slipped outside the PDM stow range.

   We therefore recommend that the next servicing mission be planned to include a manual PDM stow (including replacement of the switch guards to the NORMAL position) as part of the nominal EVA timeline.

   The Mission Director agrees.

6. The HST telemetry to be used by the crew that is dependent on the DIUs should be documented in the CSM [Cargo Systems Manual] or other ground document. A channelization table would help prevent any future confusion on the impact DIU problems will have on the crew telemetry.

   The Mission Director agrees.

7. Based on STS-61 flight experience, we recommend that the SA slew procedure be simplified to remove use of a delay timer.

8. The program should consider relocating the standard switch panel to L10 or L11 to improve flight crew access to critical payload functions.

9. We recommend that the SSE wiring be modified to telemeter command signals from the SSP to the ground via the flexible multiplexer/demultiplexers [MDMs] on the FSS.

10. We recommend that the standard switch panel harness for the PSP BYPASS switch be modified to feedback a signal to the corresponding switch talk-back that will indicate that the switch output is present.

11. Use of the ESC [electronic still camera] should be considered for future missions involving complicated tasks which might involve detailed troubleshooting tasks.

12. We recommend that the PDIP [payload data interleaver panel] relay be wired to a PF [payload operational instrumentation MDM-forward] MDM discrete to allow INCO to configure the ESC interface to the Ku system as required via up-link command.

13. We recommend that any agreements to transfer technical data between control centers be formally documented in the JOIP [Joint Operations Interface Procedures] so that such agreements receive broader exposure to and review by the integrated ops community.

    The Mission Director agrees.

14. A JOIP procedure must be written detailing appropriate personnel to be contacted for Ku-band coverage information in the event that off nominal Orbiter attitudes prevent the use of the daily Flight Plan.

15. We recommend that for future servicing missions the REPLAN and HST COORD loops be assigned an "owner" position to assist in keeping loop protocol and traffic appropriate to the loops' assigned functions.

16. We recommend that the SYSTEMS MANAGER customer position in the CSR [Customer Support Room] take more of a lead role in coordinating EVA-related inputs to the SSP FCT, and, when EVA-related decisions are made that effect the health and safety of the HST or SSE that these calls be made by the SMM [Servicing Mission Manager] or SYSTEMS MANAGER on PRIME OPS (i.e. implement the coordination plan developed by ourselves and the EVA folks).

C. SSE Operations

1. We recommend that DPC [direct power converter] load sharing characteristics for this specific set of flight units be more completely documented preflight for the operations team.

2. We recommend a reevaluation of the EVA indicator light design on both the RSIPE and ASIPE [axial scientific instrument protective enclosure] before any reflight. We also suggest the addition of the microswitch telemetry on the crew spec in the event that a similar failure occurs in the future.

3. While issues were discussed in many different meetings, we recommend that a clear summary list of all known issues/failures/concerns based on ground

testing be generated and distributed preflight by the project to the operations community.

The Mission Director agrees. See Mission Director's Recommendation No. 65.

D. Requirements Documentation

1. We suggest a process to keep the SSP and customer in sync contractually, while minimizing unnecessary paper traffic to maintain a product that is NOT used during sims or flight:

   a) Baseline the FOSA [Flight Operations Support Annex] at the CIR
   b) Proceed with development of flight documentation (without concurrent FOSA CR traffic)
   c) Execute the Flight Operations Review
   d) At conclusion of the FOR board, have the customer sign a CR that deletes procedural data from the FOSA and references the flight documentation as the official repository of payload requirements (including approved FOR DNs).
   e) Subsequent to the FOR, process 482s to payload procedures with an attached Mission Integration Change Request (MICR) to be signed by the customer or consider having customers concur directly to 482s.

2. We feel that the above approach could be applied to other ops-related annexes as well.

3. We recommend that the blank book FOSA should be modified to have book managers document payload flight rule inputs in a format consistent with the flight product.

4. We feel that the procedural parts of the FOSA format should be reworked (based on present office technology) to more closely emulate the flight products. As with the flight rule experience described above, this could enable the community to work in terms of the desired end product much earlier in the process instead of waiting until the FOR to see their inputs in flight form for the first time.

5. We recommend that the usefulness of section 5.0 of the blank book FOSA be revisited. If a user can be identified, we should find out if they are getting what they need from the existing system.

6. We encourage rigorous pursuit by the [Payload Operations] branch of office technologies which enhance our connectivity to the INTERNET to allow free

flow of written information between our organization and our customers and coworkers within MOD and SSPO.

The Mission Director agrees.

7. We recommend that a team composed of TJ [Space Shuttle Integration and Operations Office's Cargo Engineering Office (at JSC)] and representatives of SSP customer and user organizations be formed to investigate how application of present office technology might improve the distribution of technical data (mechanical and electrical engineering drawings, photographs, etc.).

The Mission Director agrees.

8. We recommend that TJ participate in the FOR process and have representation on the FOR board to assure that operations planning reflects the most recent engineering prior to start of integrated training.

E. Flight Data File Development

1. We recommend that for any future shuttle mission, if a book manager and the FDF [Flight Data File] support personnel have been industrious enough to incorporate all FOR results into the FDF in sufficient time for JIS start, regardless of the nature of the data, that the material should and must be made available to the flight crew and ground team for training.

The Mission Director agrees.

2. We propose that DSI [data source information] records are not required for payload procedures. Operating data for payload procedures are, by definition, provided by the customer. Their review of the FDF at the FOR is, in our opinion, equivalent to concurrence that the operating parameters in the FDF are correct. Subsequent changes to the FDF via 482 should not be made without customer concurrence.

F. Ground Documentation

1. CSM development should utilize electronic transfer of customer drawings and data to streamline product development. Technology still needs to be put in place to avoid unnecessary drawing regeneration at JSC.

The Mission Director agrees.

2. Early in-house production of preliminary CSMs should be utilized were feasible to improve product development.

G. Console Operations

1. We recommend that each console be equipped with existing office technology, such as a WINDOWS-capable PC on a MPSR-LAN [multi-purpose support room-local area network]. In the interim, a more central location for the one existing PC we have would be helpful. Ideally, connectivity to a PC located at the PAYLOADS console would improve real-time development and coordination of paper products (flight notes, payload status, anomaly log inputs, etc.).

   The Mission Director agrees. See Mission Director's Recommendation No. 65.

2. We recommend investigation of alternative ways of transmitting execute package information to improve print quality and usability at the remote site. One possible improvement is establishment of a remote laser printer capability from the Flight Planning System to a laser printer at GSFC, similar to the arrangement we have had between VAX computers at MSFC and a local laser printer here for Spacelab replanning products.

   The Mission Director agrees. See Mission Director's Recommendation No. 65.

3. We recommend investigation of a digital video capability that will allow low-cost transmission of opaque TV video to remote destinations for use in real-time review of up-link messages by remote centers.

4. We recommend that MEWS be modified to show MET instead of GMT on request.

5. We recommend a formal statement from DJ at the MOD Flight Readiness Review (FRR) providing the status of updates yet to be incorporated in the MOC [mission operations computer] flight load, and tracking of those open items to closure.

6. Baseline in the FOSA the specific arrangements for delivery of customer EGSE [electrical ground support equipment], including proper forms, points of contact, and preferred shipping methods.

7. We suggest that connectivity to the TMIS [Technical Management Information System] and the INTERNET be provided in the CCC [Consolidated Control Center].

Appendix C

EVA Section Recommendations

The following recommendations are excerpted from the STS-61 EVA POST FLIGHT REPORT, written by the EVA Section of the Mission Operations Directorate of the Johnson Space Center.

TASK SUMMARY

1. DF42 and CB should be involved as early as possible in all future EVA and ORU hardware design to maximize the chances of mission success.

   The Mission Director agrees. See Mission Director's Recommendations No. 14 and No. 16.

2. In a limited resource environment tool and crew aid fit verification could be limited to the primary tools and two levels of redundancy with little additional risk to mission success. In a mission with large numbers of tools and interfaces this savings would be worth pursuing.

   The Mission Director agrees.

3. All fit checks conducted by the flight crew should be considered verification - the fit should already have been confirmed by other personnel. DF42 and the flight crew should participate in fit checks as the schedule permits to increase familiarity with flight hardware. The flight crew should verify the fit of primary hardware but should not be required to fit check redundant or backup hardware.

4. If acceptable go/no go gauges are not currently available, they should be developed so that fit checking all tools to all interfaces would not be required.

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5. A single specification for PFR sockets and a single go/no go gauge reflecting flight thermal conditions should be accepted and used to fit check PFR sockets prior to their incorporation into flight hardware.

   The Mission Director agrees. See Mission Director's Recommendation No. 75.

6. [H]TV tests should be required as part of the certification process for all new complex EVA hardware that cannot be practically cycled in an unmanned chamber.

   The Mission Director agrees. See Mission Director's Recommendations No. 8 and No. 10.

7. Thermal tool fit problems should be identified prior to flight crew [human] thermal vacuum runs; these should be used to verify tool fit, not to make the initial thermal fit check.

   The Mission Director agrees.

8. The differences between engineering mockups and mass simulators and the flight hardware should be documented as early as possible and this information should be supplied to DF42 and updated as required.

   The Mission Director agrees. See Mission Director's Recommendations No. 2 and No. 33.

9. A more efficient use of limited EVA tool resources would be to eliminate duplicate efforts, particularly within the same organization, on tool development.

   The Mission Director agrees.

10. A one-hand operation end effector should be developed. The system should maintain flexibility to allow crewmembers to select their preferred mini-work station end effector.

11. For flights with similar complexity or those with numerous tools and/or possible stowage locations, early configuration control is necessary to facilitate accurate tracking and stowage.

    The Mission Director agrees.

12. A tool board similar to the HST Tools CCB, separate from the existing GFE CCB, should be established for generic EVA hardware development as well as for flights that have a need for a significant amount of new EVA tool development.

    Also see Mission Director's Recommendation No. 75.

13. Future Annex 11s should focus on providing the appropriate level of technical information without the burden of procedural details. (Also a recommendation from STS-49.)

14. Every effort should be made to minimize call-outs in the IV column. The EVA checklist should be produced in a modular form where feasible.

15. A detailed desk top payload model should be provided for DF42 as early as practical for flights of similar complexity. The model should be available when the flight crew is assigned and remain at JSC during the flight.

    The Mission Director agrees.

16. The Flight Planning System should be used to develop EVA timelines for future missions. DF42 needs a paraprofessional position to assist the EVA checklist book manager and to perform these duties for future missions.

17. DF44/RMS personnel should provide RMS translation estimates as soon as possible in the mission design factoring in appropriate adjustments for setup.

18. Timelines should be constructed from *early* water tank times combined with RMS translation estimates and other requirements such as photo/TV requirements and commanding. Although the crew will become more proficient and able to execute the tasks more quickly in later neutral buoyancy runs, the timelines should not be shortened.

    The Mission Director agrees.

19. One JIS should be performed for every scheduled EVA. This JIS does not have to be wet. This decision should be based on the degree of realism that will be achieved on the simulated video down-link. Only one pre-JIS session per EVA team is required for missions with related EVAs.

    The Mission Director disagrees. See Mission Director's Recommendation No. 21.

20. Crew schedules and training requirements for complex, multiple EVA flights should reflect the increased time requirements for WETF training exercises.

21. The HST Project needs to increase funds available for neutral buoyancy mockups. Funds will be necessary to repair mockups in addition to increasing the fidelity of HST worksites for future servicing missions.

    The Mission Director agrees. See Mission Director's Recommendation No. 33.

22. An audit should also be performed to verify that accurate fidelity is represented in the mockups. Flight like shear plates should be added to all aft shroud doors. Strong consideration should be given to fabricating a second HST neutral buoyancy mockup and leaving it resident at the NBS.

    The Mission Director agrees. See Mission Director's Recommendations No. 33.

23. A set of mockups must be present at JSC for all complex flights from approximately L-4 weeks to landing.

24. The video hard copy machine should be available for all WETF training events and underwater still photo support should be eliminated.

25. Training in a facility the size and fidelity of the NBS is required to properly develop and verify timelines and to provide end to end training. The RMS crewmember should be involved in neutral buoyancy training for future missions with significant RMS/EV [extravehicular] interaction.

    The Mission Director agrees. See Mission Director's Recommendation No. 52.

26. The trips to GSFC to observe/participate in flight hardware exercises were extremely valuable and greatly increased the probability of mission success. Training of this type should be conducted on all future missions with complex EVAs.

    The Mission Director agrees. See Mission Director's Recommendation No. 67.

27. Support of Orbiter CEITs [crew equipment interface tests] by DF42 and flight crew often results in discovery of misconfigured flight hardware and increases the potential for a safe and successful mission.

    The Mission Director agrees.

28. The payload bay walk-down should be supported by DF42 on all flights with scheduled or complex unscheduled EVAs.

    The Mission Director agrees.

29. When planning an EVA that will occur at temperatures outside the experience base, an EV crewmember from that flight should perform an [H]TV test.

    The Mission Director agrees. See Mission Director's Recommendation No. 9.

30. For complex EVAs with extensive customer interaction, the TIMELINE and MPSR SUPPORT positions should be added to the execute shift.

31. The need for the EVA TECHNICAL LIAISON position in the CSR should be evaluated on a flight-specific basis.

32. EV crewmembers should not be required to translate with devices such as the fish stringer.

33. Problems experienced in 1-G should be thoroughly evaluated to determine if they will exist on-orbit; DF42 and CB should be provided information regarding ground test problems that may result in on-orbit problems.

    The Mission Director agrees.

34. Late hardware changes need to be exhaustively examined for potential operational impacts.

    The Mission Director agrees.

35. WETF training EMUs should have stiffness added to better replicate flight conditions.

    The Mission Director agrees. See Mission Director's Recommendation No. 54.

36. Truly captive pip pins which do not require hitch pins should be used when required for temporary stowage.

<u>EMU</u>

37. Having multiple onboard copies of the EVA Prep, Post EVA, and EMU Status procedures should be considered for all multiple EVA flights.

38. Performing portions of Middeck Prep the day before each EVA is required in order to get out of the hatch on time.

39. Any EMU hardware not provided at Bench Review should be appropriately tracked.

The Mission Director agrees.

40. Future training should incorporate the leaky IDB work-around until the redesign is implemented.

41. Training should emphasize the importance of a slow repress rate to preclude an ear block and avoid the waste of consumables for depress/repress.

42. Future flights with multiple EVAs should manifest two Middeck Battery Chargers (MBCs) when the impacts of a failure would be significant.

The Mission Director agrees.

43. A change should be made to the Generic EVA Checklist to combine Post EVA and Water Recharge procedures.

44. The additional Post EVA time for reconfiguration of tools for the next EVA should be reflected in the Flight Plan. A consumables tracking cue card should be developed for all multiple EVA flights.

45. The EVA Checklist and Flight Plan should reflect the additional time required for Post-EVA Entry Prep (PE/EP) or stress should be placed during training on the amount of time required, especially if the tools are required to be restowed in their launch configuration.

46. The new EMU stowage straps should be kept in the inventory for Mir and Space Station missions that require the external airlock.

47. A training log system should be used for future, high visibility EVA flights.

48. It may be helpful in future instances to put together an outline of topics to cover for the additional EMU CWS [caution and warning system] classes. This option should be made available to all scheduled EVA flights.

49. The nominal training flow for scheduled EVA flights should have two separate CWS classes for the ETA run and final CWS classroom session.

50. A tabletop EVA Prep/Post class is not necessary unless significant changes to the procedures are required.

51. Importance needs to be placed on the schedule for EVA Prep/Post classes. The first class should be performed early in the training flow schedule. The final class should be scheduled within the last few weeks of training when all or most of the EVA tools and hardware are available and stowage is finalized.

52. For experienced EV and IV crewmembers, EMU donning should only be required for one of the EVA Prep/Post classes.

53. Any tools that are required to be taken out of the cabin during an EVA should be brought to EVA Prep/Post classes. These tools should be stowed in the appropriate location and set up during the class.

54. IV crewmembers should be requested to support both EV crewmembers' ETA chamber runs for additional Class I EMU hardware experience.

55. A scheduled EVA crew should be given as much Class I EMU experience as is possible.

56. The MBC trainer should produce the same light output as the flight units.

57. Crew schedules and training requirements for complex, multiple EVA flights should reflect the increased time requirements for WETF training exercises.

Appendix D

STS-61 Crew Comments and Recommendations

The following general comments and recommendations were made by one or more STS-61 crewmembers during various debriefings following the mission. The individual comments do not necessarily represent the opinion of the entire crew. More specific comments relating to hardware and procedures can be found in the STS-61 EVA Debriefing (JSC-26584) and in the STS-61 crew report.

- RMS II and Nitrox systems in NBS were crucial to mission preparation.
- Having to travel to MSFC's NBS was a significant negative impact.
- The NBL is needed for the Space Station Program.
- The NBL should have a direct-view flight-like window for the RMS operator. A television camera view is not sufficient.
- The Mission Specialist Training Aircraft was crucial for providing logistical support, flight training and esprit de corps.
- The new EMU glove thermal covers are great. Their flexibility is similar to that of broken-in training gloves.
- EMU cooling water flow to the arms is not needed.
- Higher air pressure in training EMUs was not sufficient to simulate greater stiffness of flight suits.
- Umbilicals and cables also exhibited surprising stiffness on orbit. Training units should be made stiffer.
- The only training facility which could represent the RMS position used for MSS change-out was the virtual reality facility.
- Payload hardware which is planned to be replaced by EVA crewmembers should be designed and verified to strict EVA requirements. Hardware which has any chance of requiring EVA replacement should be at least EVA-

compatible, with captive fasteners, e.g., but might not require an expensive verification process.

- Last-minute hardware changes, like the SA lockwire addition, must not only be shown to the crew, but also must be practiced by the crew.
- It would be beneficial to include EVA on every Shuttle mission.
- It is not essential that all crewmembers performing critical EVAs be experienced, but it is essential that EVAs be designed by experienced EVA crewmembers. Two experienced EVA crewmembers would have been sufficient for STS-61.
- The flight crew should help develop a mission's hardware, EVA tasks and EVA procedures.
- An easy-to-use computer database of EVA experience is needed.
- The Space Station Program should already be taking advantage of EVA DTOs (EVAs of Opportunity).
- The early naming of the Payload Commander is important to the development of a mission. Early crew assignment is recommended, especially the EVA crew, but it should be based on real training milestones and not some arbitrary date.
- The Mission Director was valuable in interfacing with the various STS-61 review committees.
- A Mission Director, if appointed, should be given clearer authority than was given for STS-61.
- The performance of water-training sessions in excess of six hours was essential to the mission, both for end-to-end fidelity and for crew conditioning.
- More than 6000 photographs were made during STS-61, many of them good enough for engineering evaluations. They should be used for future missions.
- Air bearing facility training was invaluable. The last minute pogo run was especially helpful.
- Planning EVAs to be no longer than six hours is the correct approach.
- We still need to better understand task timelines. We did well with our predictions, but they came largely from the EVA officers' opinions, and not straight from the WETF and NBS times.

- There was much greater time spent using training mockups (WETF and NBS) than using flight hardware (HFMS). Mockup discrepancies caused negative training.
- Problem-solving practice during training runs is valuable, even if the problem eventually is determined to be facility-unique.
- A steerable floodlight in the payload bay or on the RMS would be valuable.
- The mission would have been significantly negatively affected if the RMS had not been available.
- Retention methods for small, loose items are not adequate. Better methods should be developed.
- Jerry Ross' recommendation to pre-stage the tools and crew aids saved time.
- The HST Project should continue to pursue a method to repair light leaks. A tape should be obtained which can stick to the telescope.
- Middeck preparation should continue to be scheduled for the day prior to the EVA.
- The throttling of the air-lock equalization valve during repressurization should be standardized to help alleviate ear blockage problems.

Appendix E

EVA Management Office Recommendations

The following recommendations are excerpted from memorandum GA23-94-021, from the Space Shuttle Program's EVA Management Office.

Joint Center Operations

Issue
Unclear division of responsibilities for Nitrox activities between JSC and MSFC.

Resolution
A joint Project and Products Review Team was formed which identified, delineated and managed technical and programmatic issues between the Centers.

Recommendation
Management needs to identify very early the requirement for joint Center operations. An appropriate team needs to be formed early in the process so that issues can be identified and resolved to avoid potential cost or schedule impacts. An informal group began Nitrox development work in January of 1992, but did not receive program recognition. Earlier formation of a management-endorsed multi-Center team to attack issues head-on would likely have prevented the schedule delay of Nitrox activities at MSFC from June to October.

The Mission Director agrees. See Mission Director's Recommendation No. 62.

Thermal Environment

Issue
The EVA thermal environment exceeded EMU certification limits.

Resolution
A combination of changes in the orbit and EMU hardware resulted in the ability to successfully operate in the cold environment.

Recommendation

Establish the expected orbital environmental conditions early in the flow so that realistic simulations/analyses/tests can be performed and any needed hardware modifications started early to avoid last-minute "crunches".

EVA Planning

Issue

Roles for EVA tool responsibilities between Centers were unclear.

Resolution

Use of the GFE Tool Board under Larry Bell and the biweekly STS-61 Mission Status Telecons under Hal Lambert managed to bracket and eventually control tool issues/problems/resolution.

Recommendation

Use the recently formed EVA and Crew Equipment Project Office (ECEPO) with its Project Integration and Operations Office as the point of entry for establishing EVA requirements for the next Hubble mission. This group, overseeing the EVA Assessment Team, can realistically evaluate the tasks to be performed; judge whether or not existing tools and procedures are adequate for the envisioned tasks; suggest needed changes to existing tools; identify the need for new tools and evaluate in an iterative fashion the proposed procedures and tools as they come forward. The EVA Management Office of the ECEPO, with the guidance of the EVA Support Equipment Review Panel, will assure that the appropriate actions are taken to modify existing tools and design/fabricate/test and provide new tools.

This procedure should encompass tools suggested by GSFC as well as those from JSC. The Project Integration and Operations Office of the ECEPO should also be the focal point for the planning activities leading to the successful conduct of the next Hubble servicing mission, as it will be performing the same function for all contingency and scheduled EVA missions starting with STS-64.

The Mission Director agrees with the spirit of this recommendation. Incorporation of this plan would satisfy Mission Director's Recommendation No. 75.

The following two related recommendations were also contained in memorandum GA23-94-021.

Recommendation

Complex EVA operations using a large number of tools and crew aids require an EVA hardware forum or technical clearinghouse composed specifically of the

EVA community to resolve crew inputs and hardware modifications, additions, and deletions.

Such missions also require use of a single configuration-controlled master list of all EVA hardware on the mission, detailing quantities, part numbers, location, status, etc. GSFC concurrence is also necessary for HST.

The Mission Director agrees. See Mission Director's Recommendation No. 75.

Flight Equipment Processing

Issue

For STS-61, there were numerous changes or clarifications in requirements affecting both intravehicular (IV) and extravehicular (EV) hardware introduced late into the operational flow at the Flight Equipment Processing Contract (FEPC) facilities. The FEPC process is flexible enough to absorb some of these types of changes. However, with the volume that were introduced for STS-61, coupled with their timing, severe impacts were experienced by FEPC's resource planning and scheduling controls for both flight and training operations.

Resolution

The STS-61 training and flight were successfully supported, but with considerable difficulty.

Recommendation

Establish a focal point, having the authority, visibility, and experience to direct where and when specific tasks are to be performed. This focal point would publish an overall flight crew equipment (FCE) plan for missions similar to STS-61. When changes are being evaluated, an implementation plan should be established with gate reviews to control scheduling. If items cannot support the schedule, they are candidates for demanifesting. Critical and common milestones should be included in all plans (i.e. all changes to FCE must be completed and delivered in support of Bench Review or vacuum chamber runs, etc.). Candidate items for manifesting should be screened with regard to value added and safety risk. These types of controls would enhance centralized information and decisions and would support earlier resolution of issue.

STS-61 Lessons Learned

Project Team

Early establishment of the Project Team helped to focus the overall effort. Members from the various disciplines (project office, stress, loads, materials, safety, reliability, and quality engineering) within JSC should be assigned as part of the project team early in the design phase. The team should remain together until certification is complete. Monthly status meetings with all parties in attendance (this should include the customer) helps to identify problems early. As major milestones approach, meetings should become more frequent.

The Mission Director agrees. See also Mission Director's Recommendation No. 75.

Division CCB

Establishment of a Configuration Control Board that has budgetary flexibility assists in the process of design changes and helps to maintain schedules. Board members must include representatives from the [GFE] project office and crew.

Flight Hardware Shipments To Vendors/Other Centers

When flight hardware is requested to be shipped to other centers or vendors to support testing/fit checks, personnel from quality control and engineering should accompany the hardware. Traceability is maintained and the hardware usage and any discrepant condition can be documented.

Standardized Design/Certification Requirements

Standardized requirements documents (design and certification) should be established to assist in the design and certification of EVA hardware by other groups. Certification requirements document should establish documentation needs for certification package. Training should be established so that certification flow can be standardized. Hardware thermal certification testing should not be performed at nominal mission conditions. Worst case attitudes should be used to assure that the equipment is able to operate at all conditions. This should be identified as a requirement.

The Mission Director agrees. See Mission Director's Recommendations No. 8 and No. 75.

Digital Pagers

The use of digital pagers (local and national) should be used for major projects. The use of these assists in the quick resolution of problems when the team members are not at their normal phones or on travel.

Post Mission Support

Travel to KSC for post mission support assists in the early identification of hardware problems and expedites the return of hardware.

Early Coupled Loads Analysis

Normally, the coupled loads analysis is not finalized until L-4 months. If the analysis for the hardware comes back showing that the natural frequencies are less that 35 Hz, major additions to the hardware are required to bring the frequencies above the 35 Hz levels which severely impacts the schedules. Mini-modal testing with training hardware to verify the model and early (L-12 months) coupled loads analysis should be performed to verify that the natural frequencies are within the structural design requirements.

The Mission Director agrees.

Hardware Training Coordinator

A person was assigned for STS-61 to act as a coordinator for the hardware required to support training at the various facilities, GSFC, the WETF at JSC, and the NBS at MSFC. The use of a person in this capacity helps in assuring that the right hardware is available to support the training exercise and is also able to track the hardware. This is particularly helpful when the hardware is being supplied by multiple organizations.

Fit Check Matrix

A matrix of tool-to-tool and tool-to-hardware fit checks should be identified early in the project. This should be a formal, deliverable document that is presented and approved at the Critical Design Review. These tests should be noted as major milestones on the schedules and identification for the location of testing should be noted. Since these are major tests, time has to be allocated in the KSC schedules to account for the tests if they cannot be accomplished at the vendors facilities.

The Mission Director agrees.

Certification Approval

Final certification of tools and crew aids provided by payload suppliers should be approved by the EVA & Crew Equipment Projects Office (ECEPO) at JSC and removed from the review of the Payload Review Safety Panel (PSRP). Presentations can be given to the PSRP for information purposes only and any actions resulting be directed to the ECEPO.

See Mission Director's Recommendation No. 75.

Design Reviews

All design reviews for items of EVA Tools and Crew Aids should include representatives from Engineering and SR&QA. Previously, only representatives from MOD have attended these reviews.

The Mission Director agrees.

Resident Engineers

In the area of EVA hardware development, considerable benefit could be gained by GSFC's sending an engineer to JSC, and vice-versa, for approximately the last 12-14 months prior to flight. These resident engineers could work the intercenter issues/concerns helping to ensure that coordinated engineering decisions are made during the final months of hardware development. The resident engineers can also work to ensure that the correct design information is available to the right people. The resident engineers should be senior engineers, expert in the relevant systems. This arrangement was successfully used between JSC and Langley Research Center during the preparation for the EVA Development Flight Experiment during STS-37.

Appendix F

Crew and Thermal Systems Division's Recommendations

The following comments and recommendations were submitted by the JSC Engineering Directorate's Crew and Thermal Systems Division.

EVA Crewmember Thermal Comfort Issues

Action Implemented for STS-61: Orbiter attitude changed to less severe cold environment

Next Flight Recommendation: Use STS-61 Orbiter attitude. The primary factor in crew thermal comfort appears to have been the change to a more environmentally benign attitude.

Actions Implemented for STS-61:

- "4750" Glove Thermal Micrometeoroid Garments (TMGs), thermal overgloves, multiple arm layer Thermal Comfort Undergarments developed, tested, certified and flown.
- Liquid Cooling Ventilation Garments (LCVGs) modified to remove cooling water flow throughout the arms
- Spectra comfort gloves provided as crew option.

Next Flight Recommendation: Use STS-61 hardware configuration as needed per crew preference.

> **Mission Director's Comment: These modifications are valuable and should be made available for all potentially cold EVAs. However, to better accommodate cold case EVAs, the LCVG bypass modification which was considered but not implemented for STS-61 should also be incorporated into the EMUs scheduled to be used for cold EVAs. See Mission Director's Recommendation No. 85.**

Action Implemented for STS-61: Thermal insulation added to metal WF/PC handles when the Space Environment Simulation Laboratory (SESL) tests showed crew could not grip for required time due to cold hands.

Next Flight Recommendations:

- If use of STS-61 Orbiter attitude not possible, plan to accommodate colder environment well in advance with SESL testing and on-orbit EVAs to test new hardware mods and EMU/tool interfaces.

  Mission Director agrees. See Mission Director's Recommendations No. 8, No. 9, and No. 10.

- Improve thermal specification for payload EVA handholds. Encourage non-conducting standoffs or composite handholds.

HST Optics Contamination Issues

Actions Implemented for STS-61:

- Particulates from TMG material and non-cycled Velcro fastener analyzed early and determined not to be a concern. Velcro fastener removed from arms gloves and watch covers. Crewmembers were trained to avoid Velcro cycling.
- Off-gassing of EMU materials analyzed and determined not to be a concern except for glove/thermal overglove RTV [room temperature vulcanized rubber] coating. These were vacuum-baked to reduce the chance of contaminating the HST.
- FEPC processed all hardware as contamination-sensitive per FEMU-R-001 EMU requirements.

Next Flight Recommendation: Process next HST mission EMU hardware in the same manner.

Appendix G

John Young Comments and Recommendations

The following comments and recommendations are paraphrased from Mr. John Young's memorandum number AC5-94-05.

Lessons Learned

By August 1992, the Richard Fitts, Joe Allen and Tom Stafford reviews had produced recommendations for the training and procedures upgrades needed to make the HST SM-1 a success. Many of these recommendations eventually were incorporated, but the incorporation process took longer than it should have.

Six-hour Nitrox Training in the NBS

Apparent misrouting of funds to MSFC caused this training to slip from June to October. This mistake emphasizes the need for strict and energetic follow-up of all Hubble Mission support activities.

NBS RMS Upgrade

The installation of the RMS II at the MSFC's NBS may have been the single most important end-to-end training capability to ensure Hubble success.

The Mission Director agrees. See Mission Director's Recommendation No. 52.

Use of Virtual Reality

Virtual reality (VR) was used in the early stages of the Hubble servicing mission to help in determining the correct RMS joint angles for the various crew positions. Eventually, VR may be coupled to a pressure-suit suspension system and a part-task trainer to allow full Space Station end-to-end EVA assembly and maintenance. **Recommendation: Perform trade studies now to determine if this type of VR training capability might eliminate the need for a large water-based integrated EVA training facility (e.g., the proposed Neutral Buoyancy Laboratory).**

The Mission Director endorses this pursuit of VR and pressure suit interactive capability as a supplement to a fully integrated water training facility, not as a replacement for it.

Thermal Vacuum Real-World Conditions

Even though astronauts have complained about cold EVA temperatures for years, it wasn't until the incidence of frostbite in one of the STS-61 cold chamber runs and the cold conditions in the STS-57 EVA simulation of the STS-61 EVAs that significant corrective actions were undertaken. Greatly improved EMU glove thermal covers, better crew thermal control education, and better insulation ideas for cold operations were all implemented and will apply directly to Space Station missions, since those missions will not always have the capability to expose the crew to the earth's albedo.

Tool Certification

Tool certification issues were still being discussed as late as the week before launch. There were a number of different kinds of tool problems throughout the preparation for STS-61. **Recommendation: Establish a full-time Space Station Assembly and Maintenance Tool Chief.**

> **The Mission Director agrees. See Mission Director's Recommendation No. 75.**

Joint Integrated Simulations

There was significant initial resistance to performing Joint Integrated Simulations with the EVA crewmembers in MSFC's NBS and JSC's WETF. However, this training was accomplished and was very helpful in getting the JSC/GSFC team ready for the mission.

Hubble and Flight Crew Inputs

The STS-61 flight crew developed several time-saving ideas, one of which, the stowage of the primary tools in the Orbiter cabin, was not acted on by mission planners until Jerry Ross' independent EVA assessment also recommended it. An unusual amount of cooperation among the flight crew, JSC and GSFC personnel was integral to the success of the HST SM-1. Person-to-person communications was key to that cooperation.

EVA Timeline Production

The STS-61 EVA crewmembers were very well trained, but were not over-trained. The EVA time spent during the mission was approximately 8.4 hour in excess of the 27.1 hours scheduled. The extra time was caused both by tasks taking longer than planned, and by tasks being added during the mission. **Recommendation: For complex EVA missions conducted during Space Station Assembly and Maintenance, allow 25 per cent more time in the timeline than the tasks are expected to take.**

> **The Mission Director agrees. See Mission Director's Recommendations No. 5 and No. 6.**

Mission Director

Recommendation: "For very complex and important missions that require extra resources to meet deadlines, I believe some person with an operational staff should be assigned very early to the missions to worry the details of those missions full time. However, that person should also be given the authority, if they are going to get the responsibility, to make the missions happen right. If the Mission Director had been in the loop sooner, possibly some of the 'took longer than it should have' could have been corrected earlier."

Appendix H

PDRS POST MISSION SUMMARY

The following is the complete STS-61 Payload Deployment and Retrieval System (PDRS) post-mission summary, written by the Lead STS-61 PDRS Officer.

OVERVIEW

The STS-61 mission was launched December 2, 1993, and landed at KSC on December 13. A prior attempt to launch on December 1 had been scrubbed due to launch ceiling and KSC crosswind violations. The main objectives for the first Hubble Space Telescope (HST) Servicing Mission were threefold: (1) to restore or improve scientific capability of the HST, (2) to restore the reliability of HST systems, and (3) to validate the on-orbit servicing concept planned for HST. Specific tasks were to rendezvous with and capture the free-flying HST satellite, execute 5 EVAs in support of servicing the satellite, reboost HST to a higher altitude as propellant margins would allow, and to re-deploy the telescope into Earth orbit. Plans called for the RMS (remote manipulator system) to be utilized for all aspects of servicing the HST except for reboost.

Endeavour (OV-105) was flown with the RMS S/N 303 arm outfitted with the S/N 303 end effector. The commander of this mission was Richard Covey. RMS operators were Claude Nicollier [MS2] and Kenneth Bowersox [PLT]. EVA teams were paired off as the "odd couple", Story Musgrave [MS4] with Jeffrey Hoffman [MS3] and the "even couple", Kathy Thornton [MS1] with Thomas Akers [MS5].

POST INSERTION and FLIGHT DAY 1

The crew performed ON-ORBIT INITIALIZATION during the post-insertion phase of the flight by configuring the RMS to Temp Monitor Mode, verifying GPC DATA light function, and releasing the shoulder brace. As the arm was deselected, an "S96 PDRS ABE COMM" fault message was received. This "ABE-fault" annunciation was attributed to known timing differences which can occur between the MCIU [manipulator controller interface unit] and the arm-based electronics (ABE) whenever the arm is deselected. Similar spurious messages occurred during STS-57 with the same RMS hardware. ON-ORBIT INITIALIZATION activities were resumed as the crew completed testing the D&C [display and control] panel lighting, activating port RMS heater A, and deploying the MPMs [manipulator positioning mechanisms].

ORBIT - FLIGHT DAY 2

The crew performed RMS POWERUP to uncradle the arm as they prepared for the RMS CHECKOUT and payload bay surveys. Single, Backup, and Direct drive tests were conducted followed by checks of the RMS hand controllers, the manual augmented modes, and the operator commanded auto sequence (OCAS) mode. Also, per the PDRS procedures, checkout of the end effector in auto and manual modes was conducted along with a backup payload release test. Backup release occurred in 9.5 seconds as observed by the Mission Control Center (MCC) and subsequently verified by operator Nicollier. All RMS subsystems were observed to perform nominally.

Completion of the RMS CHECKOUT indicated a fully operational robotic arm, and the next order of business for the crew was to perform a survey of the space support equipment (SSE) in the shuttle payload bay. This type of scheduled task provides the RMS operators an excellent opportunity to familiarize themselves with the actual on-orbit feel of operating the shuttle arm while simultaneously providing post-launch inspection services of the payload bay. Arm operators are thereby allowed a chance to fine tune their zero-g technique prior to any critical arm operations. The arm was maneuvered to provide a cursory scan of various areas in the payload bay [e.g., orbital replacement unit carrier (ORUC), solar array carrier (SAC), scientific instrument protective enclosures (SIPE), etc.]. Simultaneously, berthing preparations for HST were underway. As a matter of convenience and coincidence, the arm's wrist camera was utilized to monitor portions of the pivot-up of the Flight Support Structure (FSS) ring. Upon expiration of the allotted time for SSE survey, the RMS was cradled, latched, and configured to "Temp Monitor mode".

During crew sleep, HST operations in preparation for capture and berthing continued. The STOCC (Space Telescope Operations Control Center) placed both of HST's high gain antennae (HGAs) in the stow position, however, there were no ready-to-latch indications. Consequently, the RMS flight control team began to develop a survey procedure (MSG-018) to view the HGA area in question.

ORBIT - FLIGHT DAY 3

The arm was powered up in preparation for rendezvous and retrieval of the free-flying HST. Payload ID (PLID) 1 was selected for the arm, and an OCAS (operator commanded auto sequence) executed by the crew to configure the RMS at the Poise for Capture position. Subsequently, several burns were completed by Endeavour to continue closing the gap between the Orbiter and HST. In parallel with this activity, the STOCC placed HST into a capture attitude. When the Orbiter intercepted HST, a relative pitch misalignment of about 15 degrees was observed. This misalignment was within the operational envelope of capturing HST. Bowersox reported on the A/G loop that the 15 degrees did not present a problem, and the crew proceeded to grapple HST's +V2 grapple fixture (GF1). Within the MCC, the RMS team observed a 17 second grapple and rigidization time. RMS brakes were applied as the crew reconfigured the Orbiter DAP (digital auto-pilot) and performed photo documentation.

The crew used Orbiter Loaded mode with rate hold applied in the X-axis to maneuver the HST/RMS to the FSS Hover position. After translating to the FSS Hover position, Nicollier adjusted the attitude (mainly yaw) to configure the HST for berthing. In an iterative manner, slight corrections in the Y axis were made as part of the berthing alignment. RMS brakes were cycled as PLID 2 was selected in preparation for using the FSS target as the operational reference frame for mating HST to the FSS ring. Within MCC, the Payloads officer reported the HST reaction wheels had been powered down. Berthing was commenced. About 18 inches above the berth position, Nicollier made some attitude adjustments to bias the orientation of HST prior to berthing. This was performed to take advantage of the inherent cross-coupling effects encountered with fine maneuvering of heavy class payloads. RMS brakes were applied as Story Musgrave reported to MCC the FSS was ready to latch.

The three FSS latches were subsequently closed, and the FSS umbilical was mated to the connector on HST. RMS Test mode was entered to relieve any strains on the arm that may have built up during FSS latching. Next, End Effector mode was entered, and an auto-release of HST's grapple fixture was performed to allow the end effector to back away from the berthed HST.

While the RMS operators selected Orbiter Unloaded mode to begin an HST survey, other crewmembers reconfigured the shuttle's DAP for an Orbiter attitude maneuver. The nominal RMS survey of the HST was completed in approximately 26 minutes. An additional HGA latch survey by the RMS (MSG-018) was performed to determine if the -V3 HGA latch was in good configuration. Upon viewing the latch from the starboard side (-V2), the HST customer requested a reverse angle view from the port side (+V2). While in transit from starboard to port, an elbow pitch singularity was annunciated. RMS operations were continued without consequence.

Upon completion of the post-berth surveys, the RMS was maneuvered to an approximation of the MFR [manipulator foot restraint] Extended Park position. Prior to crew sleep, a call to the crew reminded them to set the joint switch to "CRIT TEMP". This action placed the RMS in a good configuration for overnight park.

ORBIT - FLIGHT DAY 4

As the airlock was depressed for the start of EVA 1, the Orbiter's robotic arm was maneuvered from its overnight configuration towards the cabin. The crew egress was viewed with the elbow camera while Nicollier hovered the arm above the Airlock Ingress/Egress position. The RMS was brought straight down in Orbiter-Z to permit an EV (extravehicular) crewperson to tether to the arm. Subsequently, the EV crewperson (a.k.a. EV2) was transported by the arm towards the stowed MFR (manipulator foot restraint). The wrist roll joint was aligned in preparation for grappling the MFR. Auto end effector mode was used instead of manual mode to grapple the MFR contrary to the nominal PDRS procedures. No problems were encountered. Afterward, the arm was repositioned to facilitate MFR ingress. RMS brakes were applied. In preparation for MFR-attached operations, PLID 3 was selected to provide an EV2/MFR operational reference frame. Changes in the RMS joint angle data received in the MCC indicated the EV crewperson was ingressing the MFR.

The EV2 (Hoffman), after stationing himself on the MFR/RMS work platform, was maneuvered by the arm operator towards the aft portion of the payload bay to begin changeout of HST's rate sensing units (RSUs). Various RMS maneuvers at the RSU worksite and between there and the small ORU protective enclosure (SOPE) were successfully executed throughout EVA 1. The SOPE housed the replacement RSUs and stored the original RSUs for ground return. Some difficulty was encountered by the EV crewpersons with closing HST's -V3 aft shroud doors after the RSU swap was completed. As ground teams assessed this problem, Jeff Hoffman was maneuvered for the electronics control unit (ECU) changeout. Upon completion of this task, the next EVA job requiring RMS maneuvers was to change some HST fuse plugs. After the fuse plug replacements, plans called for a PFR (portable foot restraint) to be installed on HST in preparation for the next day's SA changeout task. As Hoffman was procuring the PFR from the payload bay, his movements while on the arm caused a "PDRS SLIP EP" annunciation. Slip messages may be expected whenever an MFR-attached crewmember produces a large jerking motion while RMS brakes are on. With his communications to the EVA crew, IVC (intravehicular crewmember) Tom Akers confirmed the annunciation coincided with Hoffman's movements. RMS maneuvering resumed to support installation of the PFR onto HST. Nicollier carefully avoided the deployed SAs as he positioned Hoffman to the port location for PFR installation.

Having completed the planned EVA changeouts and installations, payload bay closeout commenced with particular focus on closing HST's uncooperative aft shroud doors. Another "PDRS SLIP EP" message was annunciated while Hoffman tried to secure the door. Eventually, a PRD (payload retention device) was strapped across the doors via the doorknobs which allowed Hoffman and Musgrave to cycle the middle handle latch to successfully close the aft shroud doors.

Wrapping up the EVA, Nicollier positioned the arm near the cabin for EV crewperson tool stowage and airlock ingress. As FSS rotation and pivot began in preparation for retraction of HST's SA secondary deployment mechanism (SDM), Hoffman reported removal of the tether between the MFR and RMS end effector. This was required nightly while the MFR was attached to the RMS to comply with Orbiter rapid safing requirements. Afterwards, the arm was placed in a good MFR park configuration, but the crew quickly realized the RMS was needed to view SDM retraction per the Flight Plan.

Correspondingly, the arm was positioned to support viewing the SDM retraction. The -V2 array retraction was completed and resulted in requiring a manual stow of the primary deployment mechanism (PDM) during the next day's EVA. This could easily be supported by the RMS using nominal PDRS procedures. Due to deformation of the +V2 SA, Nicollier had to maneuver the arm clear of structural interference as the FSS rotated HST with its twisted and deployed appendage. The arm was repositioned for viewing as clearances permitted. Retraction of the +V2 array was not as successful as the first (-V2) retraction. The +V2 array was observed to have kinks and twists prior to HST grapple, so the abnormal retraction was not surprising. The HST Project agreed to plan for a manual jettison of the array during EVA 2. Upon completion of SDM viewing, the RMS was maneuvered to the MFR Extended Park position and was placed in a good overnight park configuration.

As the crew slept, MCC controllers developed a viable sequence for the next day's events. Correspondingly, an updated Flight Plan was generated.

ORBIT - FLIGHT DAY 5

The replanned EVA 2 timeline scheduled jettison of the +V2 solar array (SA) and then resumed the nominal SA changeout. Again, as the airlock was depressurized, the RMS was maneuvered to the Airlock Ingress/Egress position. Kathy Thornton ingressed the MFR on the arm, and Nicollier maneuvered her towards the SA worksite to install the jettison handle as Akers began to remove the diode box connectors. Nicollier maintained good RMS operational envelopes, and the wrist pitch reach limit was avoided by having an MFR yaw orientation of about 15 degrees. In anticipation of moving Thornton and the +V2 array to the release position, the arm operators established a safe RMS maneuvering rate by selecting PLID 4 per the PDRS procedures. Based on real-time observations, Nicollier proposed an optimum orientation to configure Thornton and the RMS for SA release. This was reported to the PDRS flight controllers who verified that his proposed maneuvering was operationally viable. Nicollier maneuvered Thornton and the array forward in the payload bay into a release orientation and waited for the release window. When the time came, Thornton released the array, Nicollier brought Thornton down in Orbiter-Z, and separation burns were executed. The array was plumed by the Orbiter jets causing it to "flap like a pterodactyl".

As the abandoned array drifted away, Thornton and Akers assumed the task of replacing the +V2 solar array. During installation of the diode box connectors to the new array, the wrist pitch reach limit was annunciated twice as Thornton was positioned to support the changeout. Both times the arm was quickly reconfigured, and RMS operations resumed with minimal impact to the EVA. Next, Thornton and the RMS operator moved the PFR from the SA worksite to the Wide-Field Planetary Camera (WF/PC) worksite prior to FSS rotation. Rotation of HST was needed to access the -V2 SA changeout. The original -V2 array was removed and replaced with a redesigned SA. Preparations continued for the next day's EVA as Thornton installed an extender onto the PFR to be used at the WF/PC worksite. Having completed the objectives for EVA 2, Bowersox maneuvered Thornton towards the airlock. Akers and Thornton proceeded to stow the EVA tools. Akers reported the MFR was untethered, and Bowersox maneuvered the RMS to the MFR Extended Park position. The arm was placed into a good overnight configuration.

ORBIT - FLIGHT DAY 6

Simultaneous with airlock depress for EVA 3, the parked RMS was activated and maneuvered to support airlock egress. Hoffman rode the arm towards WF/PC-I to install the WF/PC guide-studs upon which a WF/PC handhold was installed. To establish proper MFR/WF/PC handling rates, arm operators selected PLID 5 during the WF/PC-I blind mate and ground strap demate. With RMS assistance, the EV crewpersons removed and reinserted WF/PC-I. This allowed the EV crewpersons and arm operators an opportunity to familiarize themselves with the on-orbit handling characteristics of the large orbital replacement unit (ORU) prior to the critical installation of WF/PC-II. WF/PC-I was removed again, and as the WF/PC was maneuvered towards the Orbiter's port side, the RMS wrist yaw singularity message, "PDRS SING WY", was received twice. RMS maneuvers continued without incident, and WF/PC-I was temporarily stowed above the Orbiter's port longeron on the aft fixture of the ORU carrier (ORUC). Additional arm maneuvers were needed for the removal of a second WF/PC handhold from the forward fixture for placement upon WF/PC-II.

Integrated EVA and RMS operations continued as the radial scientific instrument protective enclosure (RSIPE) door was opened to ready the improved WF/PC-II for installation into HST. The handhold was installed on WF/PC-II, and WF/PC-II's blind mate, ground strap, and A-latch were disconnected. The crew smoothly extracted WF/PC-II from the RSIPE. As Musgrave free-floated along HST to position himself at the worksite, Nicollier and Hoffman maneuvered the replacement camera towards installation. Another wrist yaw singularity was annunciated while in transit. Nicollier continued maneuvering the RMS without experiencing any significant problems. The replacement WF/PC-II was first positioned to allow Musgrave to remove the mirror cover and then was aligned for the insertion task. Insertion of WF/PC-II proceeded with no problems, and the continuity check was successful. WF/PC-II's handhold was removed and returned to the forward fixture on the ORUC. Next, Hoffman was positioned over Endeavour's port radiator to install the mirror cover onto the old WF/PC-I. Then Hoffman was repositioned to remove WF/PC-I from its temporary stowage. After aligning the original WF/PC with the RSIPE, it was inserted and secured into the enclosure. The handhold was removed from WF/PC-I and stowed onto the ORUC aft fixture. With additional RMS repositioning, Hoffman retrieved the PFR to closeout the WF/PC worksite on HST.

Next, FSS rotation and pivot were commenced in preparation for the next EVA task of installing new magnetometers (a.k.a. magnetic sensing systems, MSS 1 & 2) on HST. The original magnetometers were powered down by the STOCC as Hoffman and Musgrave were transported to the MSS worksite by the Orbiter arm. New magnetometers were installed on HST to bypass the ailing old ones. Tests were performed which verified the new MSS 1 and MSS 2 were "alive and functional". While installing the replacement MSS 2, the EVA crew noticed the surface of the original magnetometer had peeled off in various places. Loose material was removed and stowed by Hoffman as ground controllers assessed potential complications. Completing the day's EVA objectives, Hoffman and Musgrave rode the arm down toward the Orbiter to begin the payload bay closeout. Musgrave detached himself from the arm along the Orbiter's port sill while Hoffman was maneuvered to the airlock. After completion of toolboard stowage and untethering the MFR from the RMS, Nicollier maneuvered the arm to survey the WF/PC light seals with the wrist camera. When the inspection was completed, Nicollier configured the RMS into the planned overnight park position.

ORBIT - FLIGHT DAY 7

Airlock depress was initiated, and the RMS was positioned to support airlock egress for EVA 4. Once Thornton completed ingress of the MFR, the RMS was maneuvered towards the -V2 aft shroud for the High Speed Photometer (HSP) and Corrective Optics Space Telescope Axial Replacement (COSTAR) changeout tasks. The arm was stopped momentarily as the EVA crew prepared their hardware for the changeouts. A "PDRS SLIP WY" message occurred at this time, and the crew confirmed post-flight this occurred while Thornton was twisting her body to yaw the MFR platform. Arriving at the HST, the crew proceeded to open the -V2 doors. The arm operators selected PLID 5, and Thornton was positioned into the HST cavity to handle the HSP. The EVA crew and arm operators worked together to carefully extract the phone-booth sized HSP from the telescope. Once clear of the HST cavity, a partial reinsertion was performed to practice the tight maneuvers required for insertion of the COSTAR. Afterwards, the HSP was extracted again and maneuvered towards the Orbiter port side and attached to the aft fixture on the ORUC. Following HSP removal from HST, the wrist camera was used to inspect the multi-layer insulation (MLI) within the empty HST bay.

Nicollier repositioned the RMS towards the axial scientific instrument protective enclosure (ASIPE) on the ORUC in preparation for the removal of COSTAR. As Nicollier maneuvered the RMS away from the carrier, the COSTAR was extracted clear of the ASIPE. Thornton rotated the COSTAR, and Akers removed the Deployable Optics Bench (DOB) cover. COSTAR was then transported to the HST worksite and inserted into HST. After all the latches were engaged, the wrist camera was used to videotape the worksite for post-flight documentation. Meanwhile, the STOCC reported a "good" aliveness test for COSTAR. The aft shroud doors were closed, and the RMS was maneuvered back to the ORUC aft fixture to retrieve the HSP. The HSP was removed from the aft fixture and oriented above the ASIPE for insertion. After the HSP was stowed and the ASIPE closed out, the FSS was rotated to support the DF224 coprocessor task.

Claude Nicollier positioned the RMS near the large ORU protective enclosure (LOPE) to allow the EVA crew to remove the new DF224 coprocessor. Akers and Thornton traded places on the MFR. Nicollier maneuvered Akers and the coprocessor towards the installation worksite at HST's Bay 1. After reaching the worksite, Bowersox and Nicollier traded places operating the RMS. When the coprocessor task was completed, Thornton and Akers traded places again on the MFR. Next, Bowersox used the RMS wrist camera to perform a video survey of the Bay 1 worksite prior to door closure. Upon completion of the survey, Bowersox maneuvered Thornton towards the LOPE to stow the DF224 coprocessor handles. Nicollier and Bowersox traded places as Thornton stowed the handles and Akers procured MLI from the SSE. The MLI was needed to fabricate MSS covers for the HST. Assessments by the ground team had identified thermal and contamination concerns due to the peeling surface of the old magnetometers. Resolution of these concerns required the crew to fabricate thermal covers for MSS 1 and MSS 2 from scavenged MLI. In preparation for EVA closeout, Thornton was maneuvered to the airlock for MFR egress, tool stowage, and untethering the MFR from the RMS. Subsequently, the RMS/MFR was placed in the MFR Extended Park position in a good configuration for overnight.

ORBIT - FLIGHT DAY 8

For the HST Reboost burn, the RMS was positioned to monitor the clearance between the tilted HST and the ORUC. Post-burn, as the HST and FSS were reconfigured to support the final EVA 5, the arm was placed temporarily near the MFR Extended Park position. As the airlock was depressed, the arm operators maneuvered the RMS into position for MFR ingress. Musgrave climbed aboard the

MFR, and Nicollier maneuvered the arm port towards the contingency ORU protective enclosure (COPE). After Musgrave retrieved the SA drive electronics (SADE) replacement unit from the COPE, Nicollier positioned him at HST Bay 7 for SADE changeout. Hoffman stationed himself nearby to assist in the task. During the task, a loose screw drifted away from the worksite out of EV crewperson reach towards the payload bay. Looking out the aft flight deck windows, the arm operators sighted the screw. Nicollier responded quickly and translated the arm to chase the free-flying screw. This allowed the EVA crew to recover the loose part. The arm was repositioned at the SADE worksite, and the crew continued their task.

Meanwhile, STOCC commanding to deploy the telescope's solar array (SA) Primary Deployment Mechanisms (PDMs) had been unsuccessful. This resulted in a decision to manually deploy the PDMs. The RMS team would provide a work platform for the EVA team with maneuvers similar to the previous SA changeout task during EVA 2. Executing this plan, the -V2 PDM was deployed first followed by FSS rotation to the 304° position. Then, with continued RMS support, the +V2 PDM was deployed.

The next task required opening HST's +V2 aft shroud doors for the Goddard High Resolution Spectrograph (GHRS) repair kit installation. After the crew completed the GHRS servicing, the arm was maneuvered to obtain close-out video-documentation of the worksite using the end effector/wrist camera. Subsequently, the aft shroud doors were closed, and preparations were made for the next task of installing the crew-fabricated MLI covers over the HST magnetometers.

To prepare for the MLI cover installation, Hoffman tethered himself to the MFR/RMS to hitch a ride alongside Musgrave on the Orbiter's arm. Meanwhile, the FSS was rotated for MSS 2 access. Nicollier maneuvered both EV crewpersons to the MSS 2 worksite. Completing the first cover installation, Musgrave and Hoffman enjoyed the vantage point afforded by the RMS as from inside the Orbiter Kathy Thornton rotated the FSS for MSS 1 worksite access. Bowersox took control of the arm to position the EVA team for the second cover installation. After both MLI covers for the magnetometers were successfully installed, Bowersox maneuvered the arm starboard to the SOPE to allow Hoffman to egress the arm and begin payload bay closeout. Musgrave was maneuvered to the aft end of HST (-V1) to remove the low gain antenna cover.

Nicollier resumed control of the arm with PLID 3 to transport Musgrave towards the airlock to begin EVA stowage. Near the airlock, a trash bag with a 80" tether drifted port beyond Musgrave's reach. Nicollier, Bowersox, and Covey worked together quickly to assist EV2 retrieval of the items. The equipment was recovered, and closeout of the payload bay continued. During this activity, a STOCC command had been sent to deploy HST's -V2 solar array. MCC requested the crew to configure the RMS elbow camera for SA deploy. The crew complied with the MCC request. Since the elbow camera provided the primary visual cue for positioning the RMS for tool stowage in the airlock, Nicollier requested verbal directions from

Musgrave to continue closeout activity. After all tool operations were completed, the RMS was maneuvered to the port side of Orbiter bay 5 for MFR stowage. MFR release was performed in EE [end effector] manual mode. Subsequently, Musgrave untethered the MFR from the arm, and PLID 0 was selected. Musgrave clutched the handhold on the RMS end effector and was transported back to the airlock by the RMS. Upon airlock ingress, the RMS was configured for overnight park.

ORBIT - FLIGHT DAY 9

HST was in good configuration for grapple and deployment by the RMS. All appendages were deployed with the -V3 HGA dish oriented towards the -V2 axis. This provided good clearance for the RMS grapple of the +V2 grapple fixture. FSS latches were opened, whereupon Nicollier unberthed HST from the FSS and maneuvered the RMS into the HST Release position. The crew and ground controllers made final preparations for deployment. State vectors were uplinked, and Covey readied the Orbiter for the separation burns. The STOCC readied HST for operational free flight by successfully opening its aperture door. Orbiter deadband collapse was commenced. When the time came for release, the Orbiter was set into free drift. Nicollier executed an end effector auto-release and proceeded to back the arm away from HST structure. The SEP 1 burn resulted in a .45 feet per second opening rate, and SEP 2 increased the rate to 1.2 feet per second.

After separation maneuvers were completed, the RMS was cradled and latched. Minor adjustments of the joint angles were needed to obtain the MRL [manipulator retention latch] RFL [ready for latch] indications. This was expected due to previous flight history of this hardware. With the exception of MPM stowage, RMS Powerdown was complete with RMS Heater B active.

ORBIT - FLIGHT DAY 10

RMS Heater A was activated to provide redundancy with Heater B prior to uncradling the RMS. An RMS survey of the Orbiter's water nozzle was performed during a 10.2 psia H2O dump. Upon completion of the dump, the RMS was cradled and latched. The MPMs were stowed, and the arm was configured to TEMP MONITOR mode with Heater A - OFF and Heater B - ON.

ORBIT - FLIGHT DAY 12

The RMS was deactivated 4 hours 15 minutes prior to Endeavour touchdown.

Notes of Interest

A new technique to cradle the arm was utilized on STS-61 to acquire the MRL ready-for-latch (RFL) indications. This technique was developed by RMS Training in response to previous shuttle flights where minor difficulties were encountered in maintaining the indications. First, the shoulder pitch joint is lowered until the forward RFL indications appear. Next, the elbow pitch joint is lowered until the mid RFL indications are set. If the forward RFL indications are lost during the elbow joint maneuver, the shoulder pitch joint is adjusted to regain the RFL indications. Post-flight, Nicollier and Bowersox reported this cradling technique to be very effective and helpful.

For optimal planning, the baseline mission design should strive for a consistent MFR yaw orientation to minimize crew reconfiguration. After a baseline is established adjustments to procedures may be made as specific details are understood (e.g., EVA crew arm length and reach, accessibility of worksite, EV crewperson visibility, etc.). This simplifies the RMS mission design process.

Depending on the specific mission tasks, the tip of the end effector may be the best reference frame to use when maneuvering an attached EV2 versus the standard POR [point of reference] chosen to represent an imaginary rigid EV crewperson. This may be decided with RMS operator input prior to submission of the RMS Level-C inputs.

For integrated tasks involving EVA, RMS, and payload operations personnel, coordination between PDRS, FAO [Flight Activities Officer], EVA, and Payloads is imperative to insure there are no operational conflicts. Task details must be reviewed to determine the viability of the sequence of events. For example, FSS rotation may be required for RMS/EVA access to a particular HST worksite. Task transition must be coordinated among all affected disciplines.

Claude Nicollier established a voice protocol for the EVA crew. This streamlined the communications required for maneuvering the crewmembers attached to the RMS. This is documented in the reference data section of the PDRS OPS C/L, STS-61 Flight Supplement.

MSFC's Neutral Buoyancy Simulator (NBS) was a very valuable addition to the standard RMS training facilities. A new working mockup of the shuttle robotic arm (RMS II) was developed in time to support the HST servicing mission. The NBS's large volume is the only environment available to date where the RMS operator can maneuver through nearly the full range of RMS reach while an EV crewperson is simultaneously attached to the (simulated) RMS [Note: JSC's WETF arm geometries are constrained by the WETF's comparably smaller volume.]. For this mission, the NBS was the only facility able to provide an environment where the EVA crew and arm operators could interact in a near beginning-to end simulation. Also, the interaction afforded by the NBS between arm operator and EVA crew allowed for refining the RMS procedures based on crew assessments.

Virtual reality facilities were used pre-mission by the RMS mission designer, Sal Ferrara and the STS-61 crew (Nicollier, et al) to evaluate and refine RMS positioning in support of the EVA tasks. This was also helpful in providing early opportunities for the EVA crew and RMS operators to familiarize themselves with the interactions required for this flight. Additionally, in preparation for mission support, flight controllers were given access to virtual reality facilities providing them with a "hands-on" environment to familiarize themselves with the highly complex mission.

To insert and extract large ORUs, the crew developed a technique involving iterative motion between the RMS and the EV crewperson (i.e."inchworm" technique). For example, to remove the WF/PC, Hoffman held the WF/PC in place as Nicollier pulled him back a little bit from the HST. Then Hoffman would pull a little on the WF/PC. Nicollier would pull Hoffman back some more effectively extending Hoffman's reach so that the WF/PC could be pulled some more. This iterative technique worked very well on-orbit and enabled the crew to smoothly handle various ORUs.

Albert Y. Lee
Lead PDRS Officer

Appendix I

Abbreviations and Acronyms

ABE	Arm-Based Electronics (RMS)
AC5	Mail Code for JSC's Special Assistant for Engineering, Operations, and Safety
AD	Aperture Door
AMOS	Air Force Maui Optical Site calibration test
ASEM	Assembly of [Space] Station by EVA Methods
ASIPE	Axial Scientific Instrument Protective Enclosure
CAPCOM	"CAPsule" COMmunicator (Astronaut who transmits voice communications from Mission Control to orbiting spacecraft)
CCB	Configuration Control Board
CCC	Consolidated Control Center
CCMP	Contamination Control Master Plan
CDR	Critical Design Review
CEIT	Crew Equipment Interface Test
CFE	Contractor Furnished [Orbiter] Equipment
CG	Center of Gravity
CIR	Cargo Integration Review
CITE	Cargo Integration Test Equipment
Comm	Communication(s)
COORD	COORDination voice communication loop in Mission Control
COSTAR	Corrective Optics Space Telescope Axial Replacement
CR	Change Request
CRIT	CRITical
CSM	Cargo Systems Manual
CSR	Customer Support Room
CST	Central Standard Time
CTSD	Crew and Thermal Systems Division (at JSC)
CWS	Caution and Warning System
D&C	Display and Control
DAP	Digital Auto-Pilot
DF	Mail Code for MOD's Systems Division
DF-224	Designation for HST primary computer
DF42	Mail Code for MOD's Systems Division's EVA Section
DF44	Mail Code for MOD's Systems Division's Robotics Section
DIU	Data Interface Unit

DJ	Mail Code for MOD's Control Center Systems Division
DN	Discrepancy Notice
DPC	Direct Power Converter (on HST)
DR	Discrepancy Report
DSI	Data Source Information
DSO	Detailed Supplementary Objective
DTO	Detailed Test Objective
ECEPO	EVA and Crew Equipment Project Office
ECU	Electronic Control Unit
EE	End Effector
EGSE	Electrical Ground Support Equipment
EMU	Extravehicular Mobility Unit (Space Suit)
EP	Entry Preparation
EPRT	EVA Peer Review Team
ESA	European Space Agency
ESC	Electronic Still Camera
EV	Extravehicular Designator of an extravehicular crewmember (EV1, EV2, EV3 or EV4)
EVA	Extravehicular Activity
EVASP	EVA Servicing Mission Support Plan (GSFC)
EVAWG	EVA Working Group
FAO	Flight Activities Officer
FCE	Flight Crew Equipment
FCT	Flight Control Team
FD	Flight Day
FDF	Flight Data File
FDRD	Flight Definition and Requirements Directive
FEPC	Flight Equipment Processing Contractor
FGS	Fine Guidance Sensor
FHST	Fixed-Head Star Tracker
FOC	Faint Object Camera
FOR	Flight Operations Review
FOS	Faint Object Spectrograph
FOSA	Flight Operations Support Annex
FPSR	Flight Planning and Stowage Review
FRD	Flight Requirements Document
FRR	Flight Readiness Review
FSS	Flight Support System
GA23	Mail Code for Space Shuttle Program's EVA Management Office
GF1	Grapple Fixture No. 1
GFE	Government Furnished Equipment
GHRS	Goddard High Resolution Spectrograph
GNC	Guidance, Navigation and Control
GOR	Ground Operations Review
GPC	General Purpose Computer (Carried on Orbiter)
GSFC	Goddard Space Flight Center

H2O	water
HAINS	High Accuracy Inertial Navigation System
HFMS	High Fidelity Mechanical Simulator
HGA	High Gain Antenna
HSP	High Speed Photometer
HST	Hubble Space Telescope
HTVT	Human Thermal Vacuum Test
ICBC	IMAX Cargo Bay Camera
ICHA	Integrated Cargo Hazard Assessment
IDB	In-suit Drink Bag
IGOAL	Integrated Graphics Operations and Analysis Laboratory
IMAX	Trademark for large format motion picture system
IMU	Inertial Measurement Unit
INCO	INstrument and Communications Officer
ITR	Independent Test Review
IVC	IntraVehicular Crewmember
JIS	Joint Integrated Simulation
JOIP	Joint Operations Interface Procedures
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
kbps	kilobytes per second
KSC	Kennedy Space Center
LCVG	Liquid Cooling and Ventilation Garment
LGA	Low-Gain Antenna
LMSC	Lockheed Missiles and Space Company
MBC	Middeck Battery Charger (for EMU batteries)
MCC	Mission Control Center (JSC)
MCIU	Manipulator Controller Interface Unit (RMS)
MCT	Mission Coordination Team
MDM	Multiplexer/DeMultiplexer
MFR	Manipulator Foot Restraint (Attaches to RMS)
MICR	Mission Integration Change Request
Mir	Section of Russia's Space Station (Russian word for "peace")
MLI	Multi-Layer Insulation
mm	millimeter
MMT	Mission Management Team
MOC	Mission Operations Computer
MOD	Mission Operations Directorate (at JSC)
mod	Modification
MPM	Manipulator Positioning Mechanism (RMS)
MPSR	Multi-Purpose Support Room
MRL	Manipulator Retention Latch (RMS)
MS	Mission Specialist
	Designator of specific Mission Specialist Crewmember (MS1, MS2, etc.)
MSFC	Marshall Space Flight Center
MSS	Magnetic Sensing System

MWS	Mini-Work Station (attachment to EMU)
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory (not yet built)
NBS	Neutral Buoyancy Simulator (at MSFC)
Nitrox	NITRogen/OXygen mixture (Usually oxygen-enriched air)
NS2	Mail Code for Shuttle Safety and Mission Assurance Division's Payload and Crew Equipment Branch
NS231	Mail Code for Shuttle Safety and Mission Assurance Division's GFE and EVA Section
OCAS	Operator-Commanded Auto Sequence (RMS)
OIC	Official-In-Charge
ops	operations
ORU	Orbital Replacement Unit
ORUC	ORU Carrier
OV	Orbiting Vehicular (Designator of Shuttle Orbiter, OV-105, etc.)
PAO	Public Affairs Office
PAR	Prelaunch Assessment Review (SR&QA)
PC	Personal Computer
PCR	Payload Change-out Room
PDI	Payload Data Interleaver
PDIP	Payload Data Interleaver Panel
PDM	Primary Deployment Mechanism
PDR	Preliminary Design Review
PDRS	Payload Deployment and Retrieval System
PDU	Power Distribution Unit
PE/EP	Post-EVA Entry Preparation
PF	Payload operational instrumentation MDM-Forward
PFR	Portable Foot Restraint
PHSF	Payload Hazardous Support Facility (at KSC)
PILOT	Portable In-flight Landing Operations Trainer
PINCH	Payload Integration Nominal Cost Hardware
PIP	Payload Integration Plan
	Push In, Pull out (PIP pin: a locking pin used in EVA applications)
PIT	Process Improvement Team
PLAID	Not a current acronym. Name for computer graphics laboratory maintained by JSC's Space and Life Sciences Directorate
PLID	PayLoad IDentification
PLT	Pilot
POR	Point Of Reference
POWG	Payload Operations Working Group
PRCBD	Program Requirements Control Board Directive
PRD	Payload Retention Device
PRT	Power Ratchet Tool
	Program Review Team (Chaired by Dr. Michael Greenfield)
psi	Pounds per Square Inch
psia	Pounds per Square Inch-Absolute

PSP	Payload Signal Processor
PSRP	Payload Safety Review Panel (JSC)
RCS	Reaction Control System (Orbiter's attitude control and maneuvering jets)
RFL	Ready-For-Latch (PDRS)
RIB	Right InBoard (location on Orbiter)
RMS	Remote Manipulator System
RSIPE	Radial Scientific Instrument Protective Enclosure
RSOC	Rockwell Space Operations Contractor
RSU	Rate Sensor Unit
RTLS	Return To Launch Site
RTV	Room-Temperature Vulcanized
SA	Solar Array
SAC	Solar Array Carrier
SADA	Solar Array Drive Assembly
SADE	Solar Array Drive Electronics
SADM	Solar Array Deployment Mechanism
SAS	Space Adaptation Syndrome
SDM	Secondary Deployment Mechanism
SEP	SEParation
SESL	Space Environment Simulation Laboratory
SI	Scientific Instrument
sim	simulation
SIPE	Scientific Instrument Protective Enclosure
SM	Servicing Mission
S&MA	Safety and Mission Assurance
SMM	Servicing Mission Manager
SMOWG	Servicing Mission Operations Working Group
SOPE	Small ORU Protective Enclosure
spec	specification
SR&QA	Safety, Reliability, and Quality Assurance
SSE	Space Support Equipment
SSP	Space Shuttle Program
SSPO	Space Shuttle Program Office
SSRP	Systems Safety Review Panel
STA	Shuttle Training Aircraft
STOCC	Space Telescope Operations and Control Center
STS	Space Transportation System Designator for a Space Shuttle Mission (e.g., STS-61)
sync	synchronization
TDRSS	Tracking and Data Relay Satellite System
TJ	Mail Code for the Space Shuttle Integration and Operations Office's Cargo Engineering Office (at JSC)
TMG	Thermal/Micrometeoroid Garment (Protective covering for EMU)
TMIS	Technical Management Information System
TRR	Test Readiness Review
VR	Virtual Reality

WETF	Weightless Environment Training Facility (at JSC)
WF/PC	Wide Field/Planetary Camera
WG	Working Group
WIT	WF/PC Installation Tool

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13. ABSTRACT *(Maximum 200 words)*

To ensure the success of the complex Hubble Space Telescope servicing mission, STS-61, NASA established a number of independent review groups to assess management, design, planning, and preparation for the mission. One of the resulting recommendations for mission success was that an overall Mission Director be appointed to coordinate management activities of the Space Shuttle and Hubble programs and to consolidate results of the team reviews and expedite responses to recommendations. This report presents pre-mission events important to the experience base of mission management, with related Mission Director's recommendations following the event(s) to which they apply. All Mission Director's recommendations are presented collectively in an appendix. Other appendixes contain recommendations from the various review groups, including Payload Officers, the JSC Extravehicular Activity (EVA) Section, JSC EVA Management Office, JSC Crew and Thermal Systems Division, and the STS-61 crew itself. This report also lists mission events in chronological order and includes as an appendix a post-mission summary by the lead Payload Deployment and Retrieval System Officer. Recommendations range from those pertaining to specific component use or operating techniques to those for improved management, review, planning, and safety procedures.

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